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REPORT

FUEL CELL POWER SYSTEM AND EQUIPMENT BAY FOR HIGH ALTITUDE, SUPER-PRESSURED, POWERED AEROSTAT (HASPA)

OPERATIONAL MANUAL

Prepared for

Naval Surface Weapons Center
White Oak
Silver Spring, Maryland 20910

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DIRECT ENERGY CONVERSION PROGRAMS
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This contract is for the development of an H_2-O_2 fuel cell system for use as the power source in the HASPA feasibility program. Besides propulsive power, the fuel cell must supply power to navigation and communication systems and other electronic components. The HASPA is a lighter than air unmanned platform that operates continuously at high altitude for long periods of time, and maintains an assigned station through powered maneuverability.

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1.0 INTRODUCTION

This manual provides the operating instructions for Fuel Cell Module FS-2. The ion exchange membrane fuel cell module is produced by the General Electric Company, Direct Energy Conversion Programs, 50 Fordham Road, Wilmington, Massachusetts.

Leading particulars for the fuel cell module are given in Table I. Figure 1 shows a plot of normal output performance.

This manual also provides a description and operating instruction for the equipment bay, which includes the heat rejection system and the power system/heat rejection electronic controls.

Table I

Fuel Cell Module Particulars

1.	Number of stacks	1
2.	Number of cells/stack	34
3.	Number of membrane-electrode assemblies/module	68
4.	Membrane-electrode assembly area	0.35 ft^2
5.	Number of M and E's in parallel (per cell)	2
6.	Equivalent cell area (item 4 x 5)	0.70 ft^2
7.	Cell assembly thickness	0.35 inch
8.	Coolant temperature	130°F
9.	Oxygen pressure	60 psig
10.	Hydrogen pressure	56 psig
11.	Weight (wet)	103.5 lb
12.	Maximum power within voltage	3 KW
13.	Container length	21 inches
14.	Container diameter	13 inches
15.	Oxygen Consumption #/Amp-Hr	0.0224
16.	Hydrogen Consumption #/Amp-Hr	0.0028
17.	Product water generation cc/amp-hr	11.5

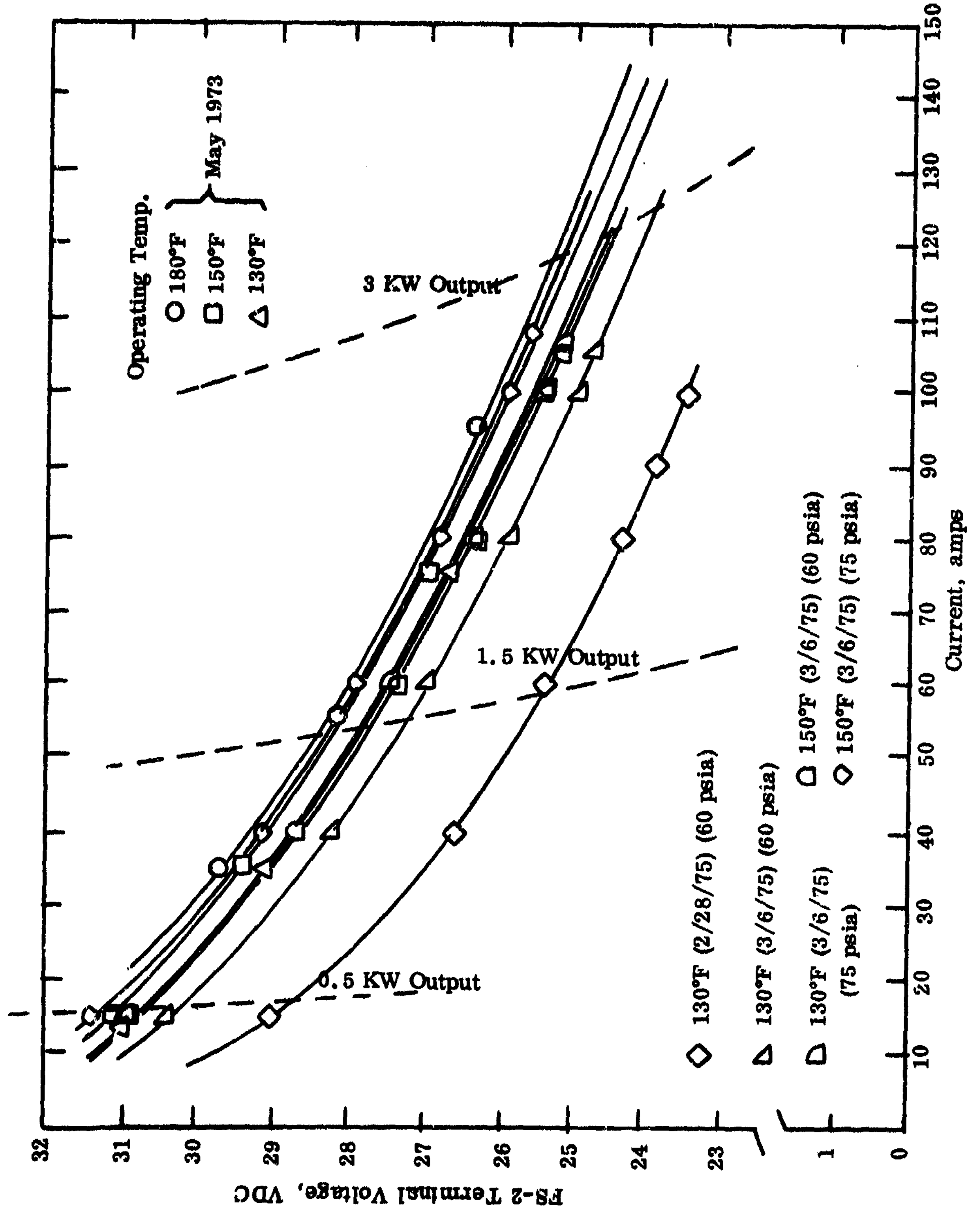


Figure 1. FS-2 Performance Data

2.0 DESCRIPTION OF FUEL CELL POWER SYSTEM

2.1 General

The heart of the fuel cell power system is the fuel cell module which is contained within, controlled and/or supported by, or provides power for the following:

Equipment Bay
Coolant System
Cryogenic Gas Supply
Product Water Tankage
System Electronic Controls
Electrical System

Figure 2 is a schematic of the power system fluid system.

Figure 3 is a block diagram of the HASPA power system electronics (system control unit).

Table II - HASPA Power System Input Commands
Table III - HASPA Power System Instrumentation Readouts

2.2 Required Operating Equipment and Materials

The following materials and equipment are required for operation of the fuel cell power system:

High purity hydrogen gas, conforming to GE/DECP Specification D50GN301

High purity oxygen gas, conforming to GE/DECP Specification D50GN302

Deionized water conforming to GE/DECP Specification D50GN318

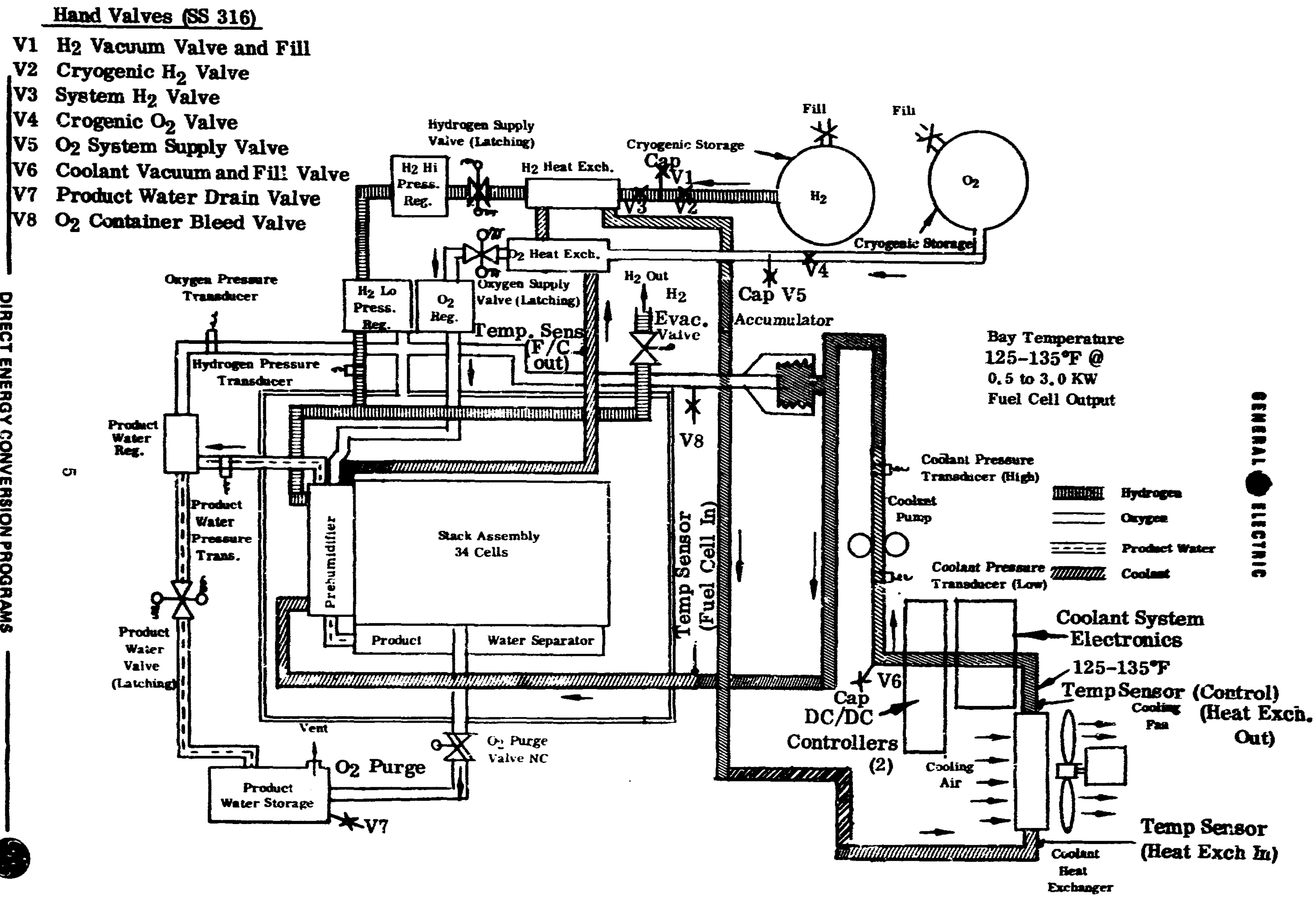
Vacuum pump, Cenco Cat. No. 90510 or Equivalent

High purity nitrogen gas conforming to GE/DECP Specification D50GN303

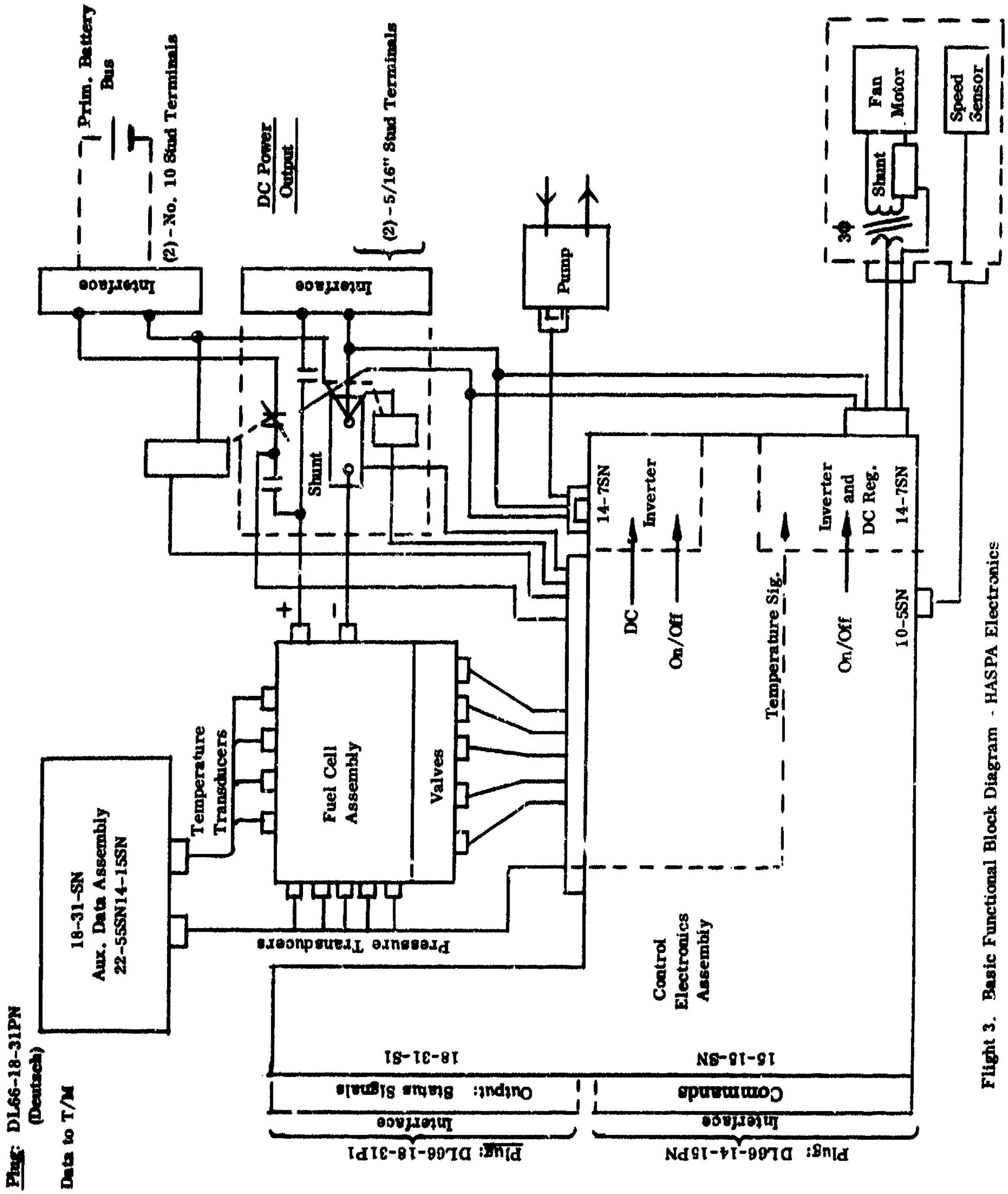
High purity helium gas conforming to GE/DECP Specification D50GN304

Variable load bank or propulsion system load

Regulated D.C. power supplies



Flight 3. Power System Fluid Schematic (Fuel Cell Powered Flight)
Figure 2.



Flight 3. Basic Functional Block Diagram - HASPA Electronics

Figure 3.

Table II

HASPA Power System Input Commands

Channel	Function	Type *
31	H_2 Inlet Valve	L
32	O_2 Inlet Valve	L
33	H_2O Valve	L
40	Load Contactor	L
41	Coolant Pump	L
42	Fan	L
43	H_2 Evacuation Valve	L
44	O_2 Manual Purge	M
45	Emergency Shutdown Reset/Override	L

* L = Latch

M = Momentary

An input command signal will be a T/M equipment relay closure. A voltage signal from the fuel cell control assembly will be grounded by the appropriate T/M relay contact and will remain grounded for the entire period the command is in force. Opening the T/M relay contact will correspond to an opposite command (i.e., H_2 Inlet Open - Closed Contact; H_2 Inlet Close - Open Contact).

Emergency shutdown reset will allow the system to be operated remotely following an emergency shutdown for diagnostic or other purposes.

Table III

HASPA Power System Instrumentation Readouts

TM Channel	Parameter	Signal Display
1	H_2 Pressure	Meter 1
2	H_2 Inlet	Light Red
3	O_2 Pressure	Meter 1
4	H_2 Inlet VPI Open	Light Green
5	H_2O Pressure	Meter 1
6	O_2 Inlet VPI Closed	Light Red
7	O_2-H_2 ΔP	Meter 2
8	O_2 Inlet VPI Open	Light Green
9	O_2 Δ H_2O ΔP	Meter 2
10	H_2O VPI Closed	Light Red
11	Fuel Cell Coolant In Temperature	Meter 3
12	H_2O VPI Open	Light Green
13	Fuel Cell Coolant Out Temperature	Meter 3
14	H_2 Evacuation Energized	Light Green
15	Heat Exchanger Coolant In Temperature	Meter 3
16	Load Contactor Closed	Light Green
17	Heat Exchanger Coolant Out Temperature	Meter 3
18	Pump On	Light Green
19	Fuel Cell Voltage	Meter 6
20	Emergency Shutdown Indication	Light Red
21	Fuel Cell Current	Meter 5
22	O_2 Purge Valve Open	Light Green
23	Cooling Fan Speed	Meter 4
24	Coolant ΔP	Meter 2

Input commands and controls compatible to Table II

Instrumentation readout compatible to Table III

1000 Hz imedpance bridge - Figure 13

RTV 108, silicone adhesive

2.3 Configuration of the Fuel Cell Power System

The fuel cell module (FS-2) is the heart of the power system. This module successfully completed a sixty hour operational checkout on March 6, 1975 demonstrating adequate performance of the fuel cell stack and auxiliary components for HASPA flight requirements. (See HPR-13, dated March 31, 1975, Fuel Cell Module FS-2 Test Report.)

Fuel cell stack (FS-2) contains thirty-four "back-to-back" cell assemblies and a reactant prehumidifier. Figure 4 is an assembled view of the stack. Figure 5 is a partial cross-section of a cell assembly. Figure 6 shows the fuel cell stack assembly.

The cell assembly design utilizes an edge current collection technique which allows, with only minor design changes, the selection of series or parallel interconnecting of cells to provide a wide range of voltages for a given power requirement. The stack FS-2 configuration produces a nominal 28 VDC.

The end plate reactant prehumidifier (Figure 7) is utilized to saturate the reactants with water prior to introduction into the active areas of the cell assemblies and thus prevents cell drying. Controls are not required for this device since humidity is automatically controlled by the supply of product water and the exit coolant temperature.

The fuel cell stack also contains a major portion of the product water removal system. Product water is removed from the cathode electrode by a series of wicks which transport the water to porous glass separator tubes at the base of the stack. A differential pressure of approximately 3 psi is maintained across the tube walls by a pressure regulator. This allows the passage of liquid water through the tubes without the passage of gas. Each cell cathode compartment contains a single sheet dacron wick which terminates on one of the porous glass separators.

Stack FS-2 is mounted in a shortened Space Shuttle container and mated with the additional accessory components to form the fuel cell module.

2.3.1 Functional Systems

The fuel cell stack incorporates four operating systems: hydrogen, oxygen/product water, coolant, and electrical.

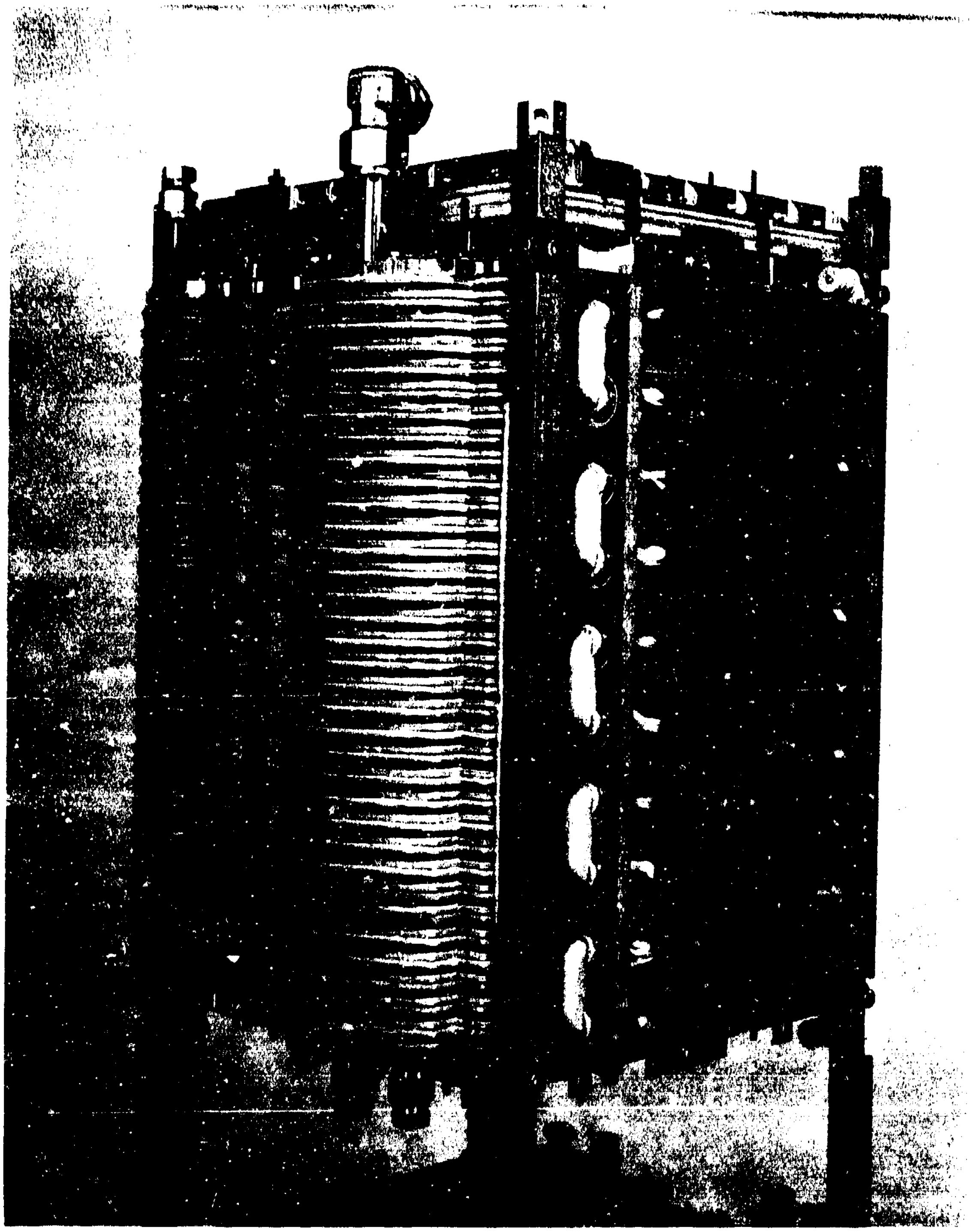


Figure 4. Fuel Cell Stack No. 2 (34 Cells)

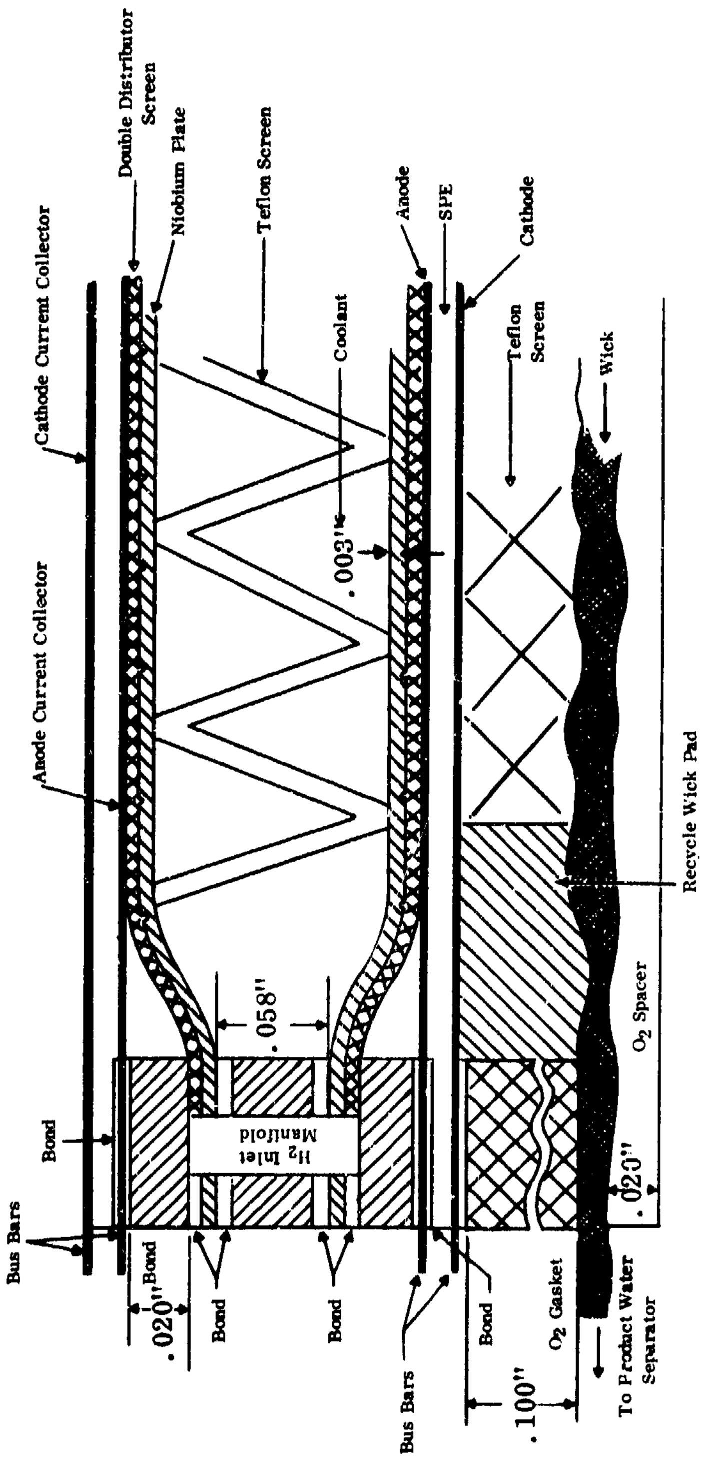


Figure 5. Cross-section of O_2 Frame, Spacer and Cell Assembly

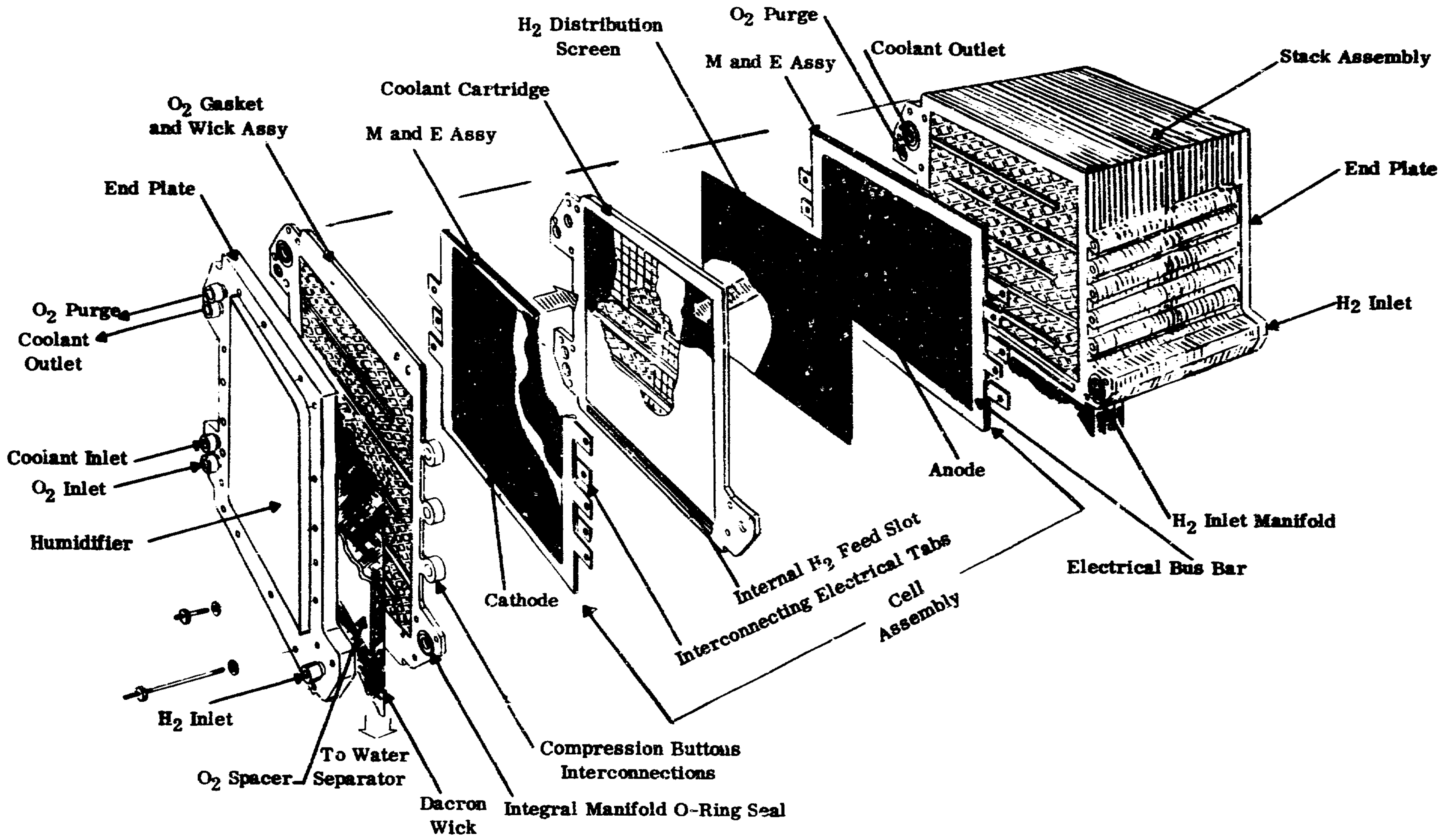


Figure 6. Fuel Cell Stack Assembly

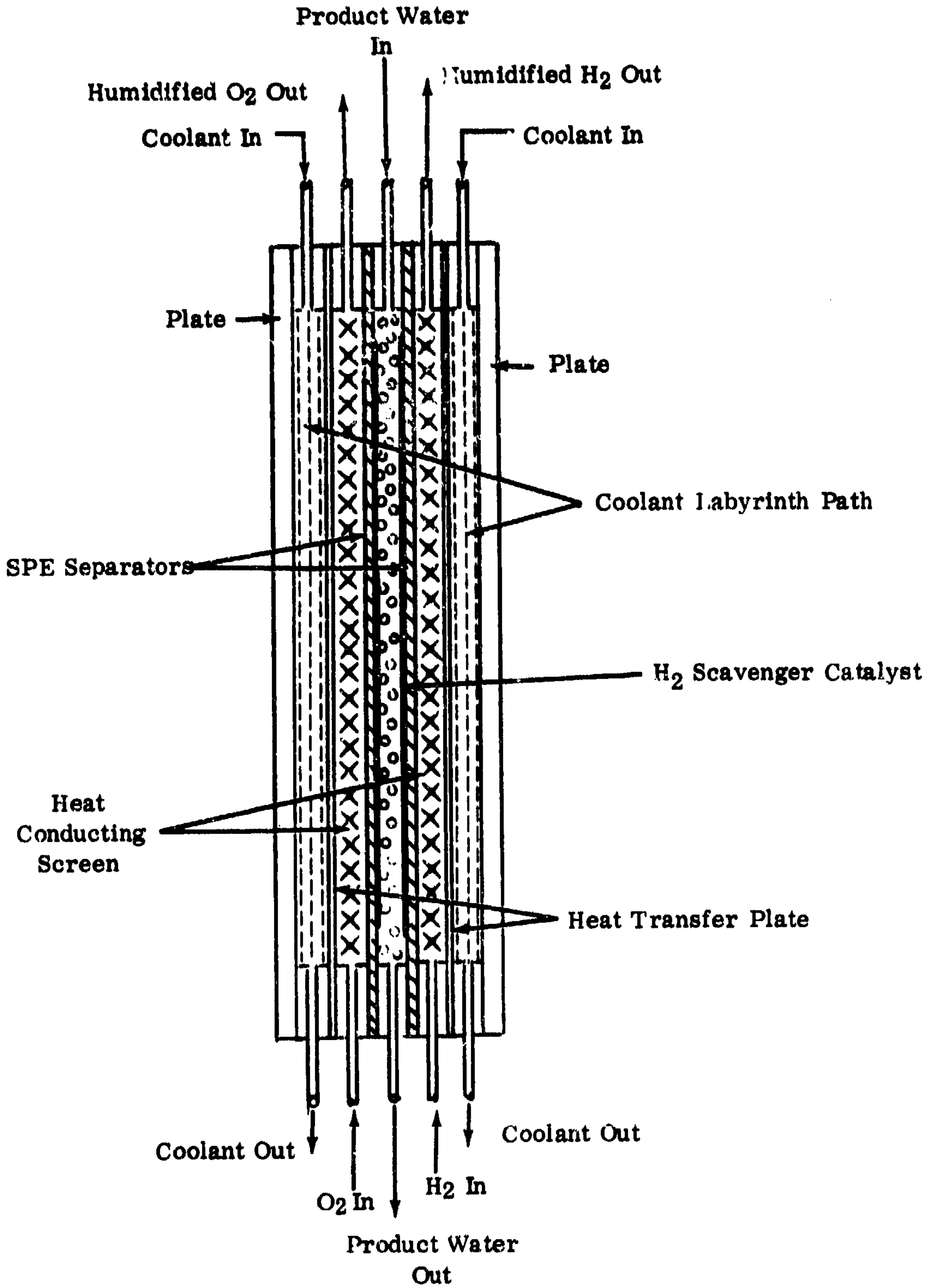


Figure 7. Reactant Humidifier Schematic

Hydrogen gas is used as the fuel, and oxygen gas is the oxidizing agent. The hydrogen-oxygen gases are reacted in the presence of a catalyst and produce electrical energy and product water. Waste heat is removed from the stack by coolant fluid which is pumped continuously across the cells within the individual cell assembly coolant cartridges. The following paragraphs will discuss each of the four systems in terms of its operating characteristics and interactions with other systems.

2.3.1.1 Hydrogen System

The hydrogen cryogenic storage and supply tank is provided and maintained by Beech Aircraft Corporation. It is connected to the GE/DECP hydrogen heat exchanger. A hydrogen latching supply valve provides ON/OFF control to the pre-set hydrogen high pressure regulator, which in turn supplies the hydrogen low pressure regulator. The H_2 low pressure regulator provides H_2 to the hydrogen pre-humidifier at a pressure 5.0 psi lower than the oxygen reference pressure. The H_2 pressure is measured by means of a pressure transducer and a 0 to 5 volt output signal provided.

Prehumidified hydrogen gas enters the fuel cell stack at the end plate H_2 in port. The hydrogen is then directed into the integral stack hydrogen manifold, through individual cell assembly feed tubes, into the cell assembly manifold slot, and finally across the anode side of the membrane-electrode assembly.

Flow distribution of the hydrogen gas from cell to cell is not a problem as that system is purely a demand system. This pure demand system is possible because no purging or bleeding of the hydrogen system is necessary even with the maximum allowed inerts and contaminants within the hydrogen supply. The inerts and contaminants, which flow into the anode gap along with the hydrogen gas, are eliminated by natural diffusion through the solid polymer electrolyte membrane into the oxygen system where they are carried out of the stack during the normal oxygen purge.

A hydrogen evacuation valve is provided for H_2 side evacuation and startup and for possible vacuum startup during flight.

2.3.1.2 Oxygen/Product Water System

The oxygen cryogenic storage and supply tank is provided and maintained by Beech Aircraft Corporation. It is connected to the GE/DECP oxygen heat exchanger. An oxygen latching supply valve provides ON/OFF control of oxygen to the oxygen regulator which in turn provides oxygen to the oxygen prehumidifier at the pre-set regulated operating pressure.

Prehumidified oxygen gas enters the fuel cell stack at the end plate O_2 in port and is then directed into the integral stack manifold to the cells through individual restrictor tubes, across the cathode face of the M and E assembly, out the oxygen outlet tubes, into the stack outlet manifold, and finally out of the stack oxygen purge port.

The electronic control circuitry operates the O_2 purge on a fixed cycle of every 16 ampere-hours for a 8-10 second interval at a 70 Liter per minute rate at 60 psig.

Product water removal is achieved by a dacron wick which in each cathode compartment terminates out one of the porous glass separator tubes. A 3 psi differential pressure across the tubes forces passage of liquid water from the stack and through the product water separator, flow continues through the reactant prehumidifier, and the excess water is passed through the product water regulator and product water latch valve to the four tank product water storage system which is of sufficient volume to store mission requirements.

Pressure transducers in the O_2, H_2 and H_2O systems provide TM meter readouts of H_2, O_2, H_2O, $O_2 \Delta H_2$, and $O_2 \Delta H_2O$ pressures.

2.3.1.3 Coolant System

The coolant system utilized for the fuel cell power system is shown schematically in Figure 2. This system will be modified for the Battery Powered Flight and the Solar Powered Flight as shown in Figures 8 and 9.

Deionized water is utilized as the fuel cell coolant fluid.

The coolant high and low pressure transducers provide a meter readout of coolant flow which is indicated in values of coolant and differential pressure.

Temperature sensors are located in the fuel cell coolant in, fuel cell coolant out, heat exchanger in, and heat exchanger out fluid lines for indication of thermal conditions and subsequent control.

The fuel cell power supply coolant system is also utilized for maintaining safe operating temperatures for the DC/DC converters, system electronic controls, and the internal environmental temperature of the equipment bay.

The amount of cooling air passing through the heat exchanger varies with cooling fan speed which is automatically controlled from temperature sensor inputs. The cooling system normal operating temperature is 130°F.

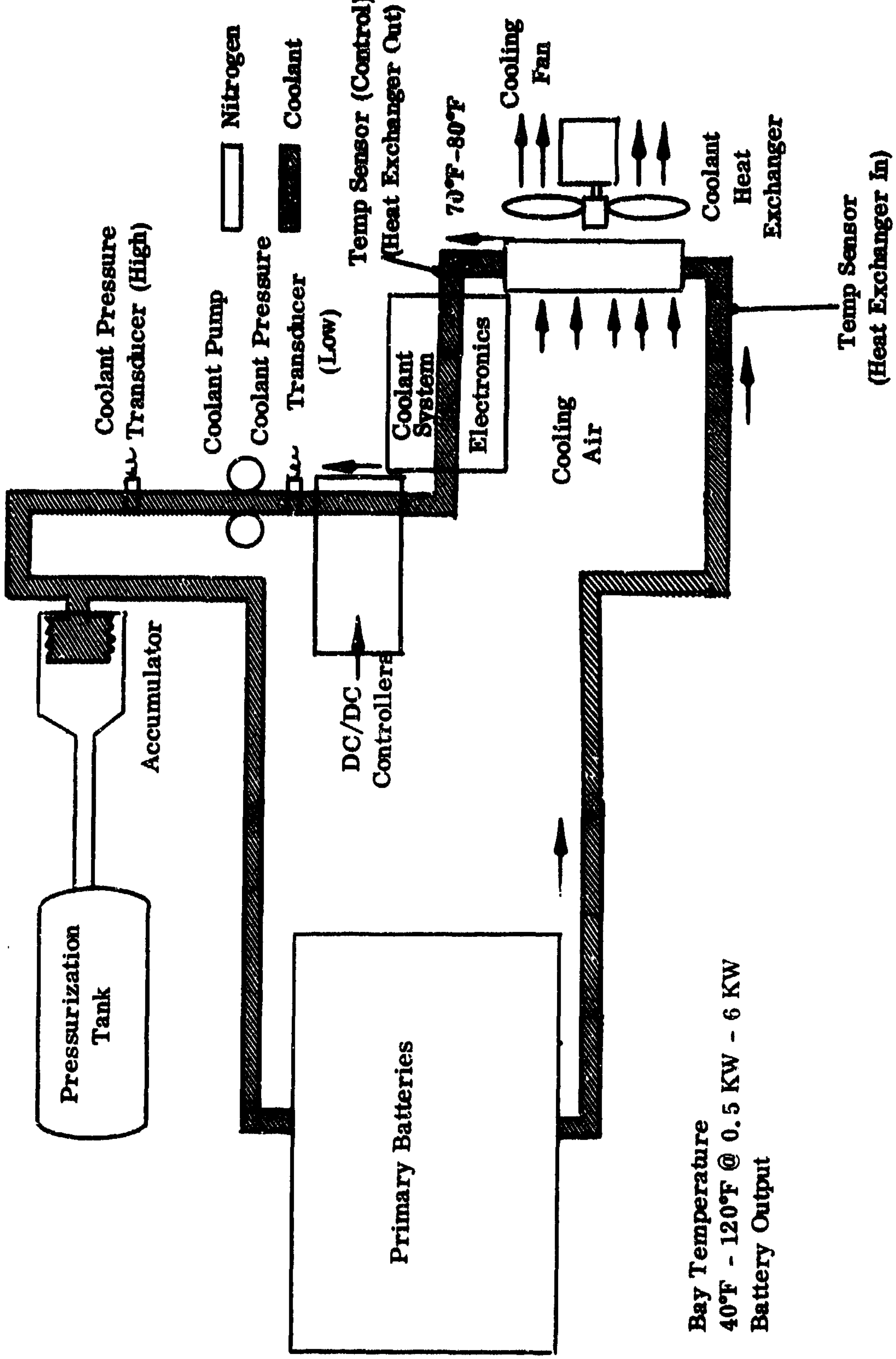


Figure 8. Cooling System Fluid Schematic (Battery Powered Flight)

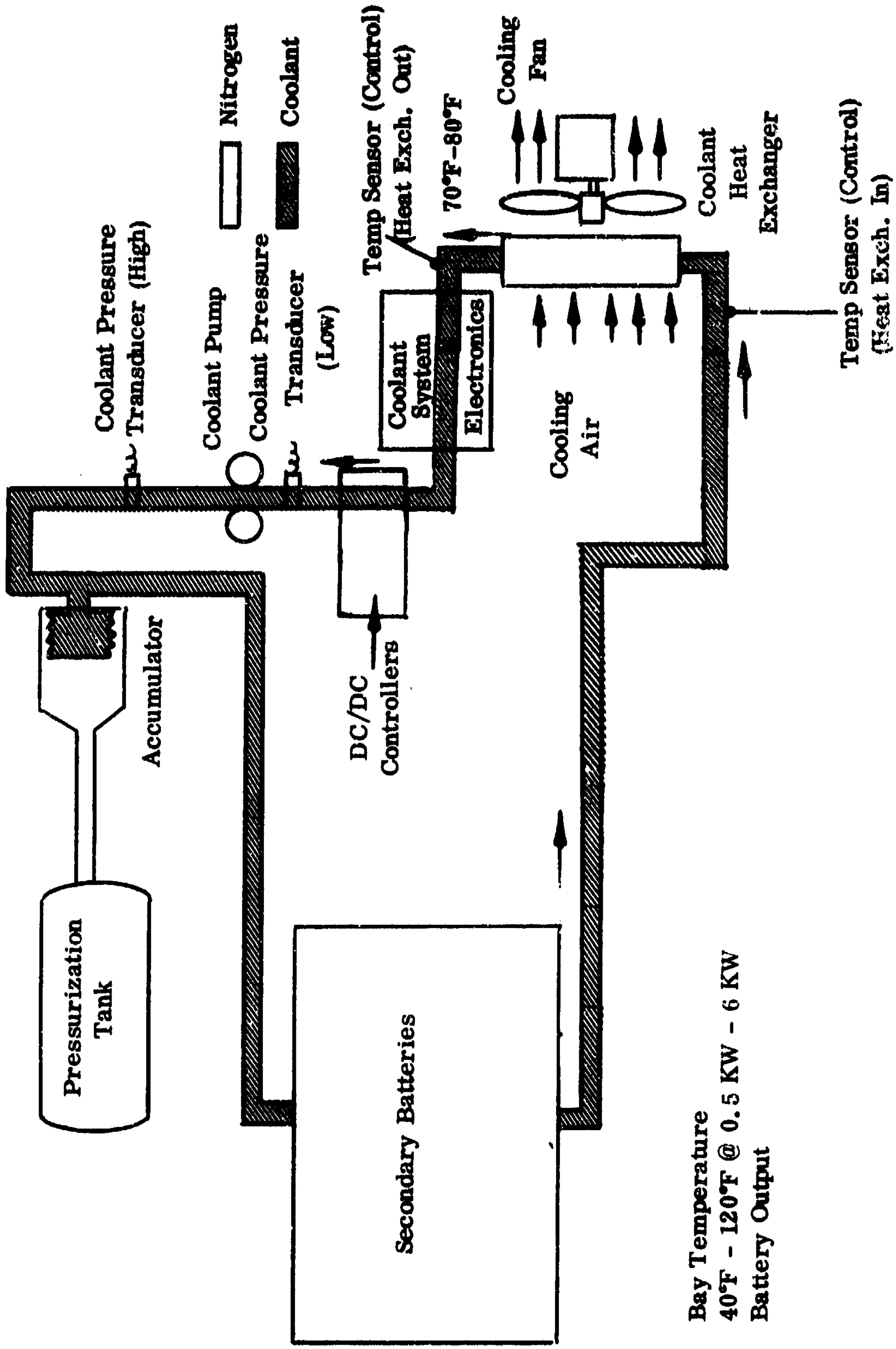


Figure 9. Cooling System Fluid Schematic (Solar Cell/Battery Powered Flight)

2.3.1.4 Electrical System

The module power connectors are utilized for operating in the fuel cell mode and are utilized as power input terminals in the electrolysis start-up option. This option is discussed in Paragraph 4.2.6.

An individual cell voltage connector is available on the fuel cell module, but shall not be utilized for normal flight operations.

The basic function block diagram, HASPA Electronics (Figure 3), shows the method of interconnection of basic components and supporting accessory units of the fuel cell power supply system.

The control circuitry, input commands, and instrumentation readouts are listed in Tables II and III.

The data acquisition accuracy is ± 2% and will be logged at a rate of one data point/second.

All items in Table III may be selected for constant monitoring, either on a meter readout or by light display (See Figure 10).

Fuel cell operation is controlled by means of several valves, a coolant circulating pump, a temperature controlling fan, a main power contactor and an auxiliary power contactor.

In order to provide remote operation, the system will respond to nine remote T/M commands. These commands, together with sensor generated pressure, temperature, VPI, current, voltage and speed signals are utilized with suitable logic to perform all necessary control for continuous mission operation.

2.3.1.4.1 Valve Operation

Latch operation is used to control the H_2 inlet, O_2 inlet and H_2O drain valves. These call for short duration pulses to be applied to the actuating solenoid. The pulse is removed after the valve has been actuated. Operation of a Valve Position Indicating Switch terminates the drive to the solenoid and provides a status indication to the appropriate T/M channel. The T/M signal (a relay closure) must be continuously maintained without the presence of an emergency shutdown signal in order to maintain the above latch valves in an open position. When either an open T/M relay contact is obtained or an emergency shutdown signal is generated in the F/C control assembly, the valve will be latched in the closed position.

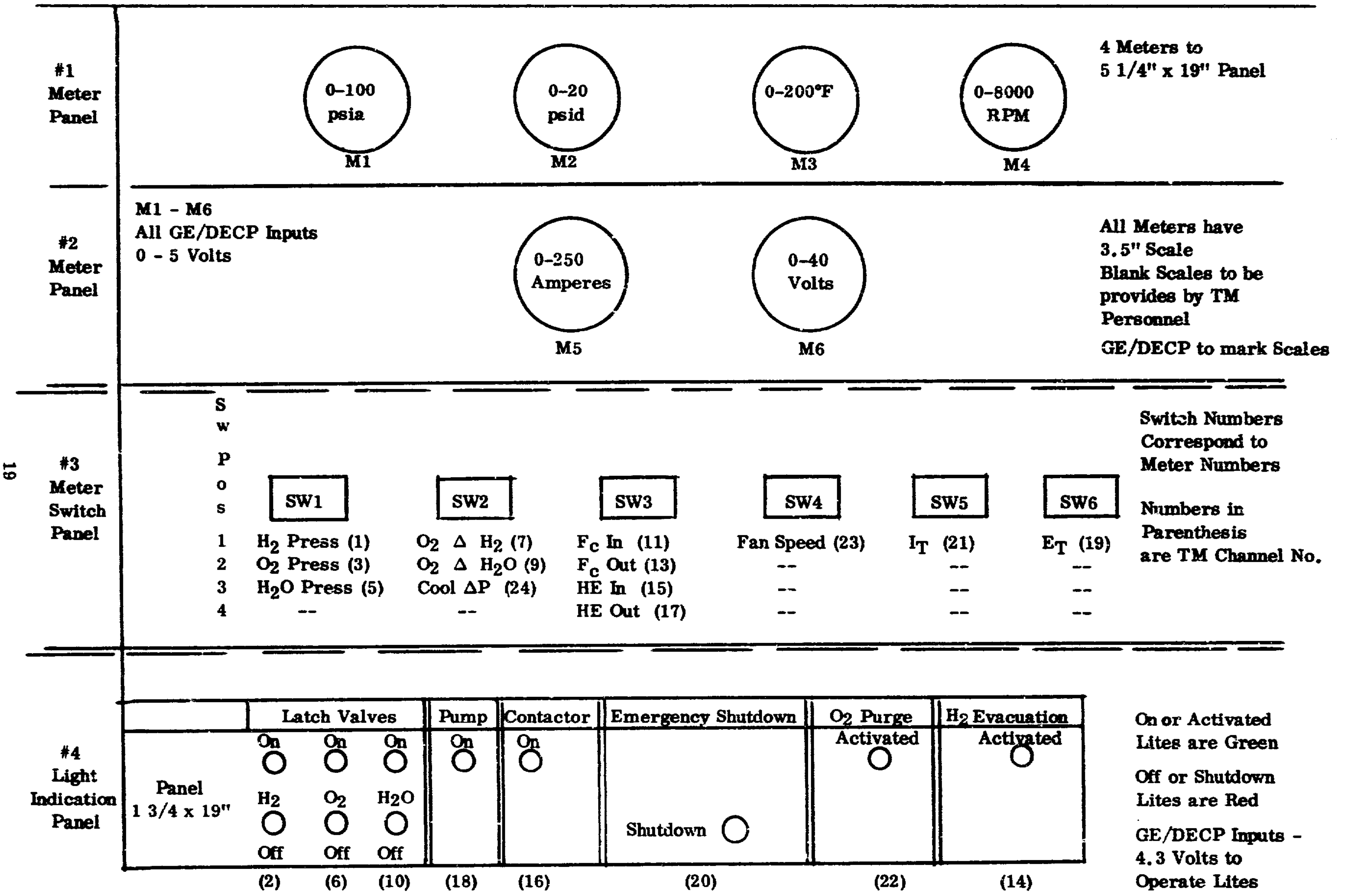


Figure 10. HASPA TM Instrumentation Readout Panels

The T/M command must be removed in order to maintain the valve in the closed position when the ESD is reset or overridden. If not removed, the "open" command will cause the valve to open as soon as the ESD reset/override is actuated.

Basic latch valve operation is shown in Figure 11. Q01 and Q03 are Darlington drivers which directly pulse the latch valve solenoids. Q02 and Q04 provide a transition between the 5 volt logic and the 28V latch solenoid bus. These latter transistors are driven directly from the logic gates UO2b and UO2d.

When the command input signal is low ("0") and the ESD bus is low ("0") and the ESD bus is low UO1d produces a "1" into UO2a. In the event the OPEN VPI signal is "1" (i.e., valve not open) a "1" will be produced out of UO2b, thereby driving the open solenoid until a "0" is produced by the OPEN VPI switch. When this happens the output from UO2b will change to a "0", and hold at this level.

In the event the ESD bus is switched to a "1" level, actuation of the open solenoid will cease and be prevented from occurring regardless of the command signal into the logic.

A close signal is obtained when the command bus is across an open relay contact. This places a "1" on the input to UO1d and UO1b. On UO1d the effect is to disable that channel. However, on UO1b the effect is to produce a "1" out of UO1c and a "1" out of UO2d as long as the CLOSED VPI signal remains at a high level. When the VPI indicates valve closure the drive signal is removed and the latch solenoid will remain closed. Either the ESD signal or the "CLOSE" signal will produce this result.

2.3.1.4.2 Driven Valves (Contactor)

The H_2 Evacuation Valve and the O_2 Purge Valve are driven continuously while in operation. This is accomplished by the circuit of Figure 12. An actuate command ("0" into U20c) will produce a drive signal at Q13 as long as the ESD bus is also at "0" level. A "1" on the ESD bus or the command bus will remove the valve drive and allow the valve to close.

2.3.1.4.3 O_2 Purge System

The O_2 Purge Control is an automatic/manual system which will perform a system purge after either manual or automatic initiation. Manual initiation will result from an input command. The purge duration will depend on the length of time the command is in force and will terminate with the command termination. Automatic initiation is controlled by the load current level out of the fuel cell. An analog/digital integrator will measure approximately sixteen amp-hours of fuel cell operation and will initiate an eight to ten second purge and reset following the purge.

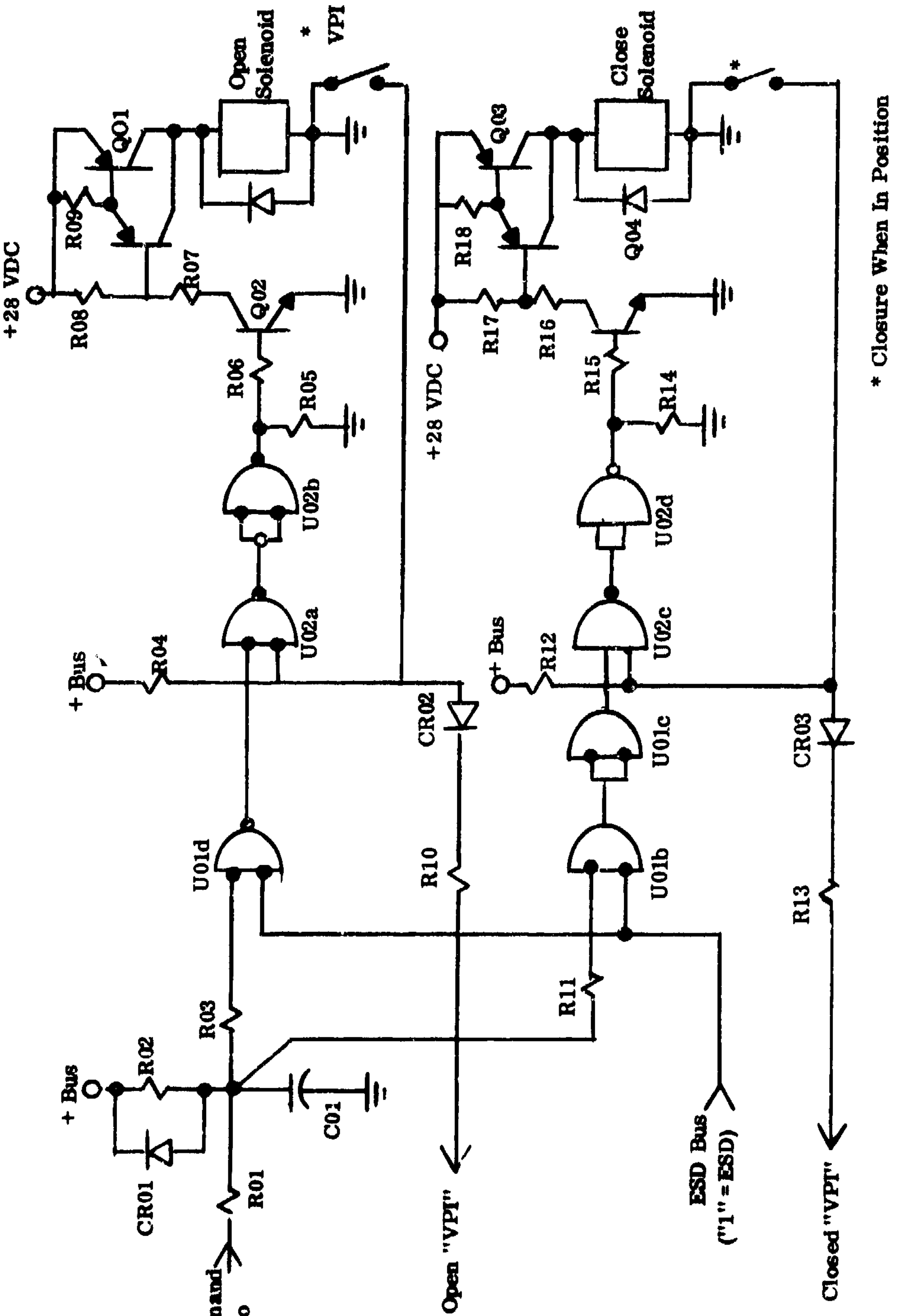


Figure 11. Latch Valve Electrical Diagram

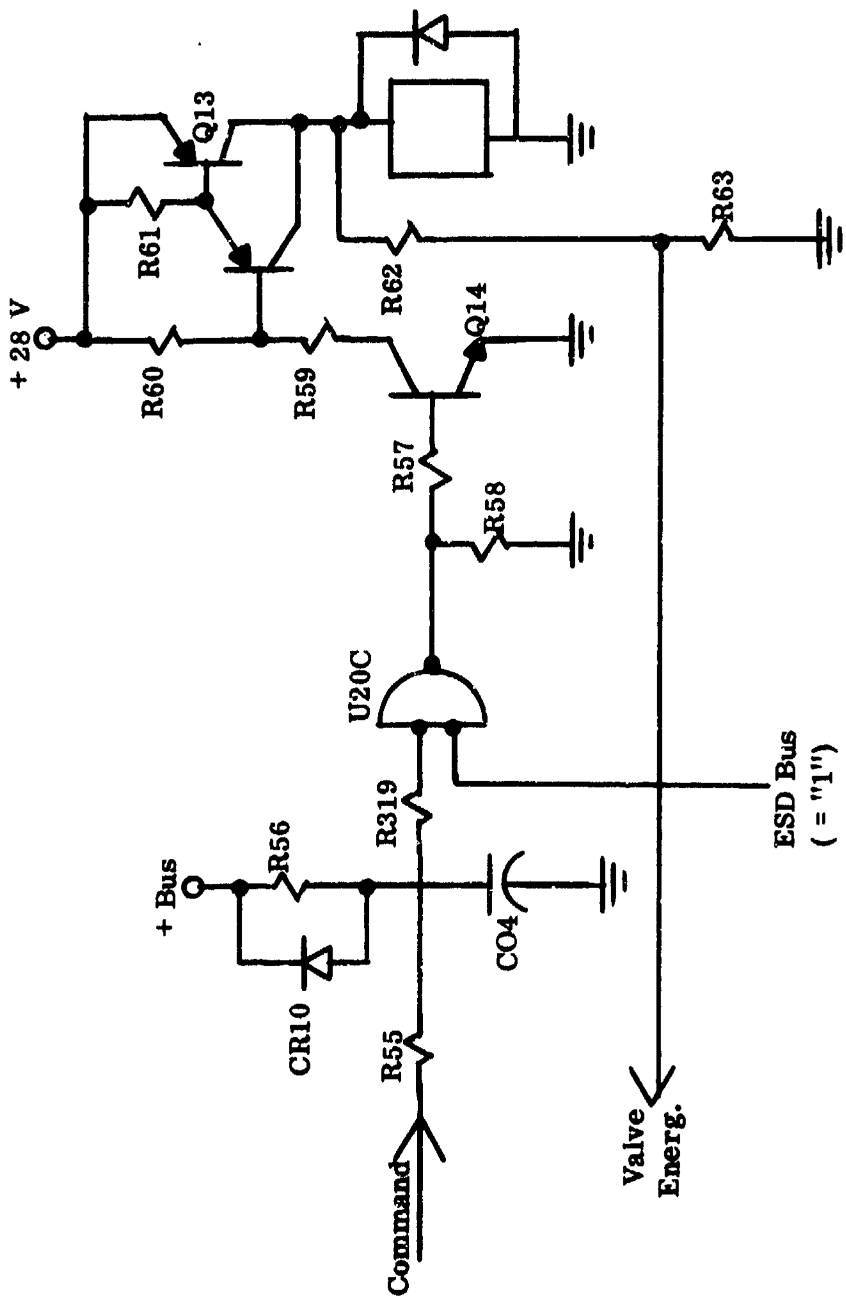


Figure 12. Direct Valve (Contactor) Drive Electrical Diagram

Detailed circuitry is shown in Figure 13. A current signal is supplied by the current shunt in series with the fuel cell load current. This signal is integrated in operational amplifier UO8a and capacitor C10. When the output of UO8a reaches a suitable level, op-amp UO8b resets the integrator through R174. The pulse which is produced is counted in UO9. When sufficient counts have been accumulated U10 will produce a six second pulse at the input of U21d. The output of gate U21d, in addition to generating a signal to open the valve, also resets the counter UO9. Manual operation, on command, operates through gates U21d and U21c and the drive transistors Q16 and Q15 in a manner similar to the previous valve drives.

2.3.1.4.4 Emergency Shutdown

Emergency Shutdown is initiated when fuel cell output voltage drops below a predetermined minimum. At this minimum voltage the ESD bus level is raised to a "1" level and held until the ESD reset/override command is initiated. Raising this bus level closes all valves, opens the contactor and disables the pump and fan. Operation of any of the other commands is prevented as long as this bus remains at a high level. Initiating an ESD reset/override command will reset this bus and restore the system immediately to the status dictated by the present command configuration. It is very important, therefore, to preset the command configuration prior to giving a reset command in order to prevent undesired system operation. The detailed circuitry is shown in Figure 14.

At startup, the flip-flop U22 is set by the action of the power on reset circuit U12b, U12C, U12d, and associated input components. A pulse is generated at startup setting FF U22 to produce a "1" at the input to UO5d and a "0" on the ESD bus. Once on line, a low fuel cell voltage into comparator U41b will produce a signal into "R" on U22 raising the ESD bus level and producing shutdown. In order to activate the system an ESD reset command is required which will introduce a high "set" level to U22. "Set" is dominant over the "Reset" and will allow the system to be reactivated while the ESD reset/override command is maintained. When stack voltage has risen above the shutdown level the ESD override command can be removed.

2.3.1.4.5 Temperature Transducer Amplifiers

Temperature readings are generated from a platinum resistance sensor using the circuitry as shown in Figure 15. The platinum resistance is in the feedback circuit of the first operational amplifier, making the output of the amplifier directly proportional to the sensor resistance. The second amplifier and its associated passive components is a scaling amplifier with gain and level controls R183 and R180, respectively. These are set to produce an output voltage of 0 to 5 VDC for 0 to 200°F.

2.3.1.4.6 Pressure Transducer Amplifiers

Pressure transducers of the strain gage type feed a signal into a scaling amplifier of the type shown in Figure 16.

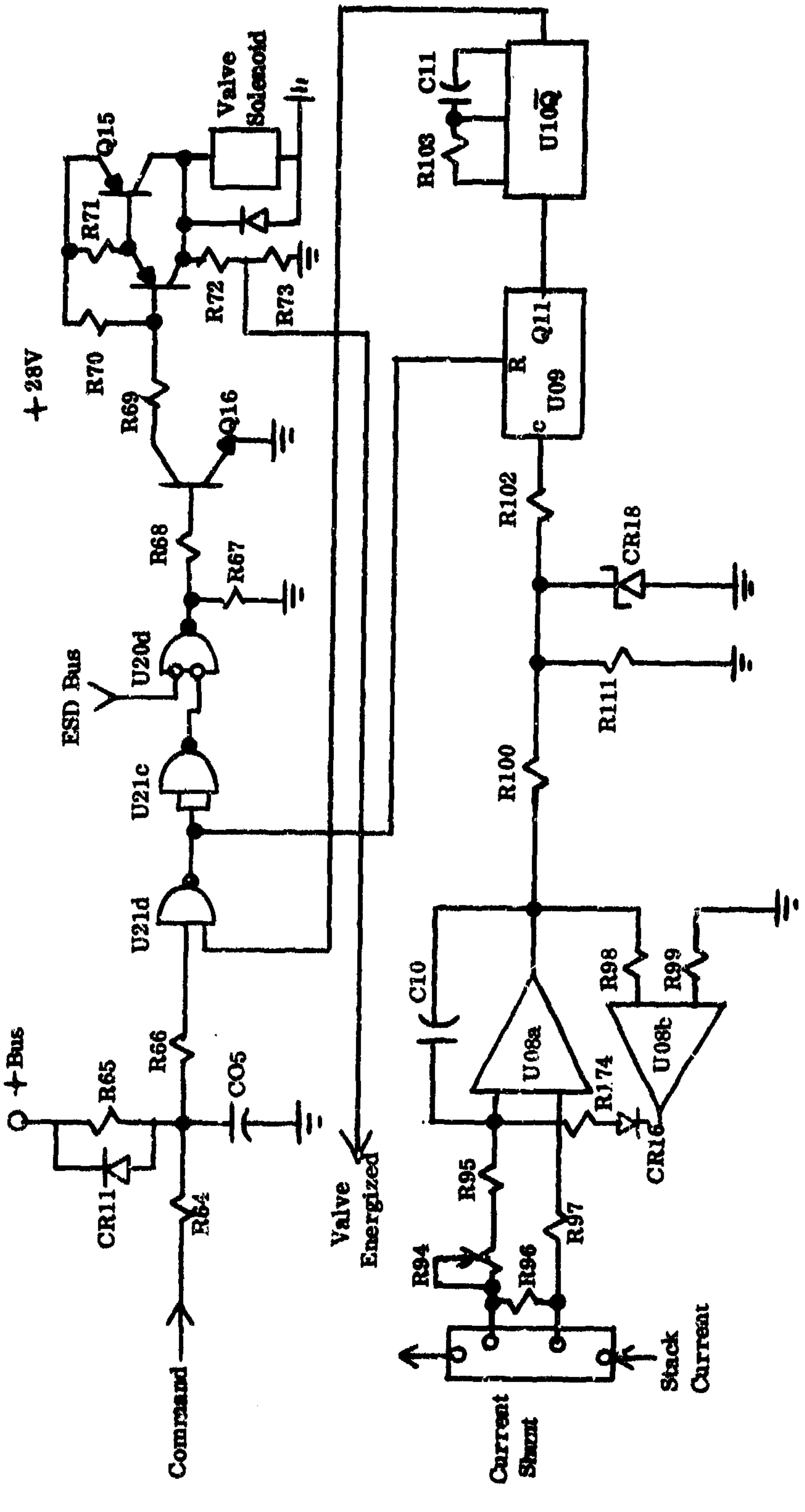


Figure 13. Purge Timer and Interval Integrator Electrical Diagram

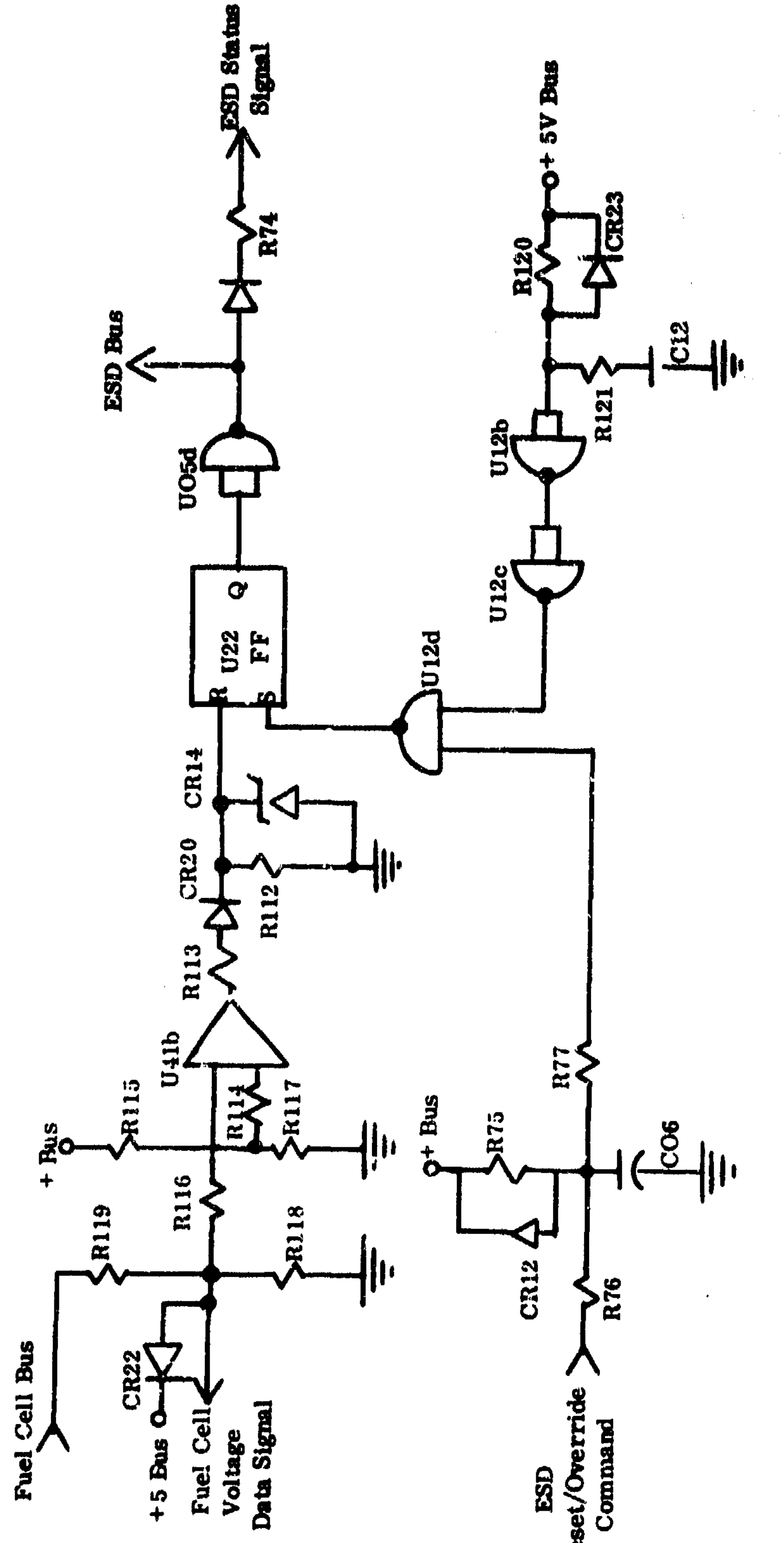


Figure 14. Emergency Shutdown Circuitry Electrical Diagram

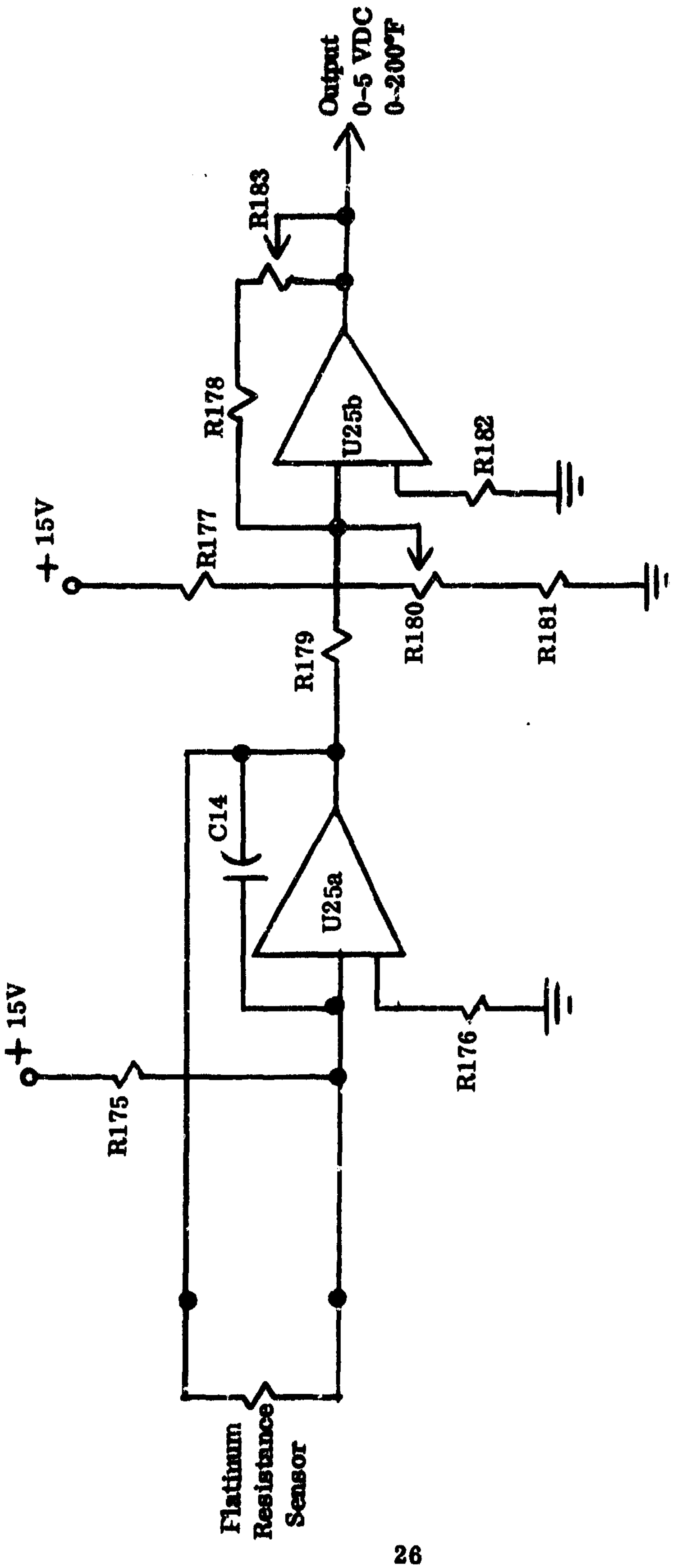


Figure 15. Temperature Transducer Amplifier Electrical Diagram

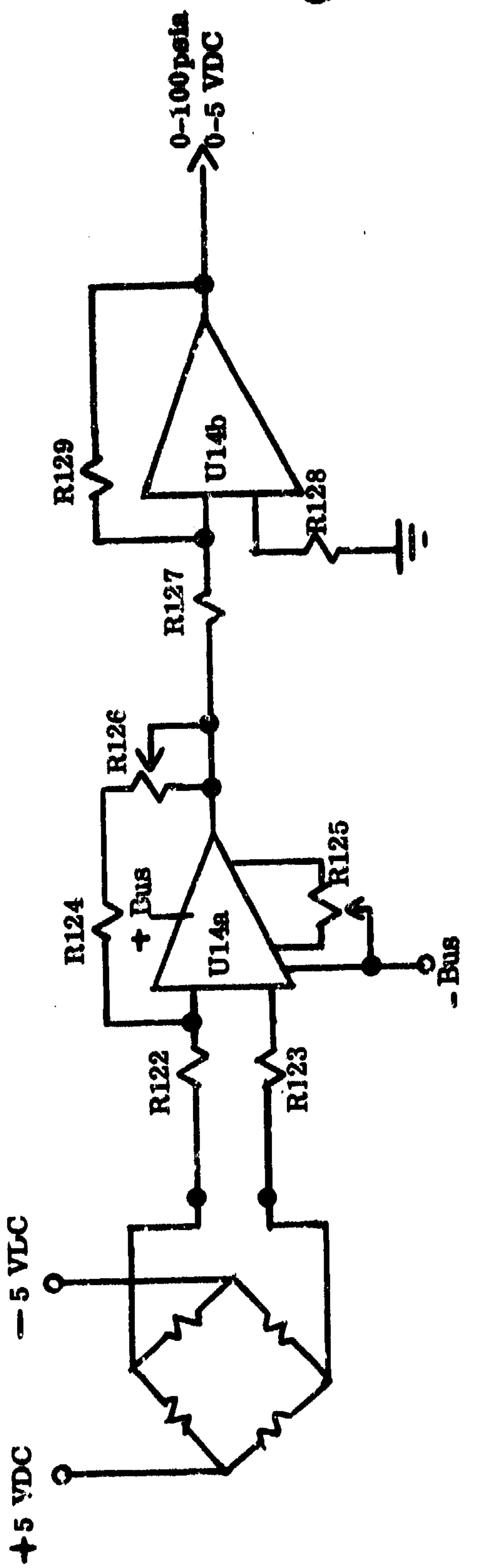


Figure 16. Pressure Transducer Amplifier Electrical Diagram

Two operational amplifiers with their required passive components give the required gain to produce 0 to 5 VDC for a 0-100 psia pressure input; R125 adjusts the zero level and R126 sets the overall gain.

2.3.1.4.7 Pump Inverter

The coolant pump is operated by a fixed frequency inverter which operates from the fuel cell bus voltage. Nomonal line-to-line voltage to the motor is 19.6 VRMS, and the operating frequency is 300 Hz.

Detailed circuitry is shown in Figure 17 and Figure 18.

In the circuit of Figure 17 the frequency rate of 300 Hz is generated by the unijunction oscillator operating at 1800 Hz. This pulse repetition frequency is fed into a decade counter. Logic encoding is provided by the subsequent gates which also allow for logic ON/OFF control. The necessary drive matching is provided by the subsequent signal transistors and associated components for two types of operating power switch (A and B).

The switch timing diagram is shown in Table IV.

Table IV

	Switch					
Step	A	B	C	D	E	F
0				X	X	
1	X			X		
2	X					X
3			X			X
4		X	X			
5		X			X	

X = Switch Conducting

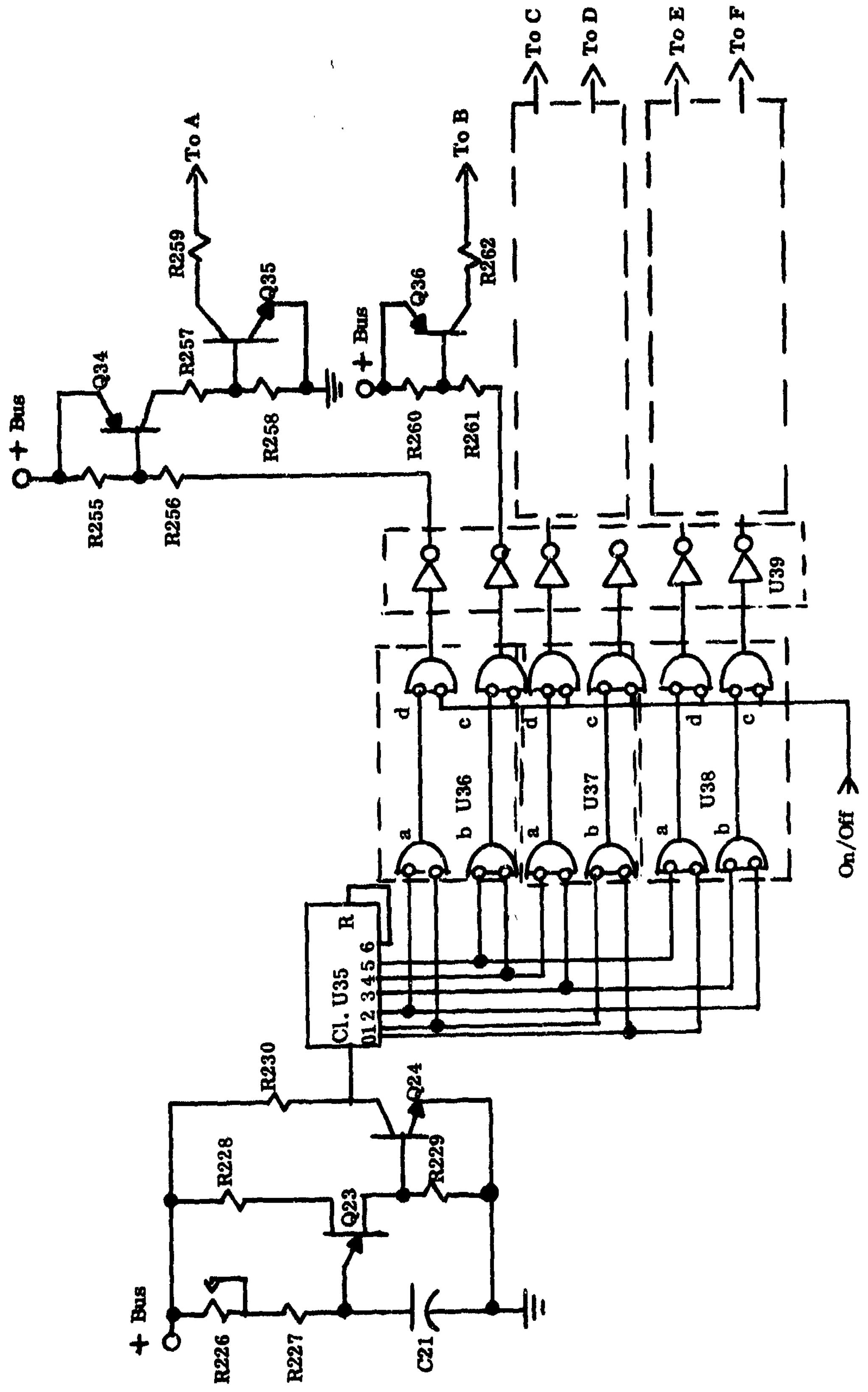


Figure 17. Pump Inverter Logic Electrical Diagram

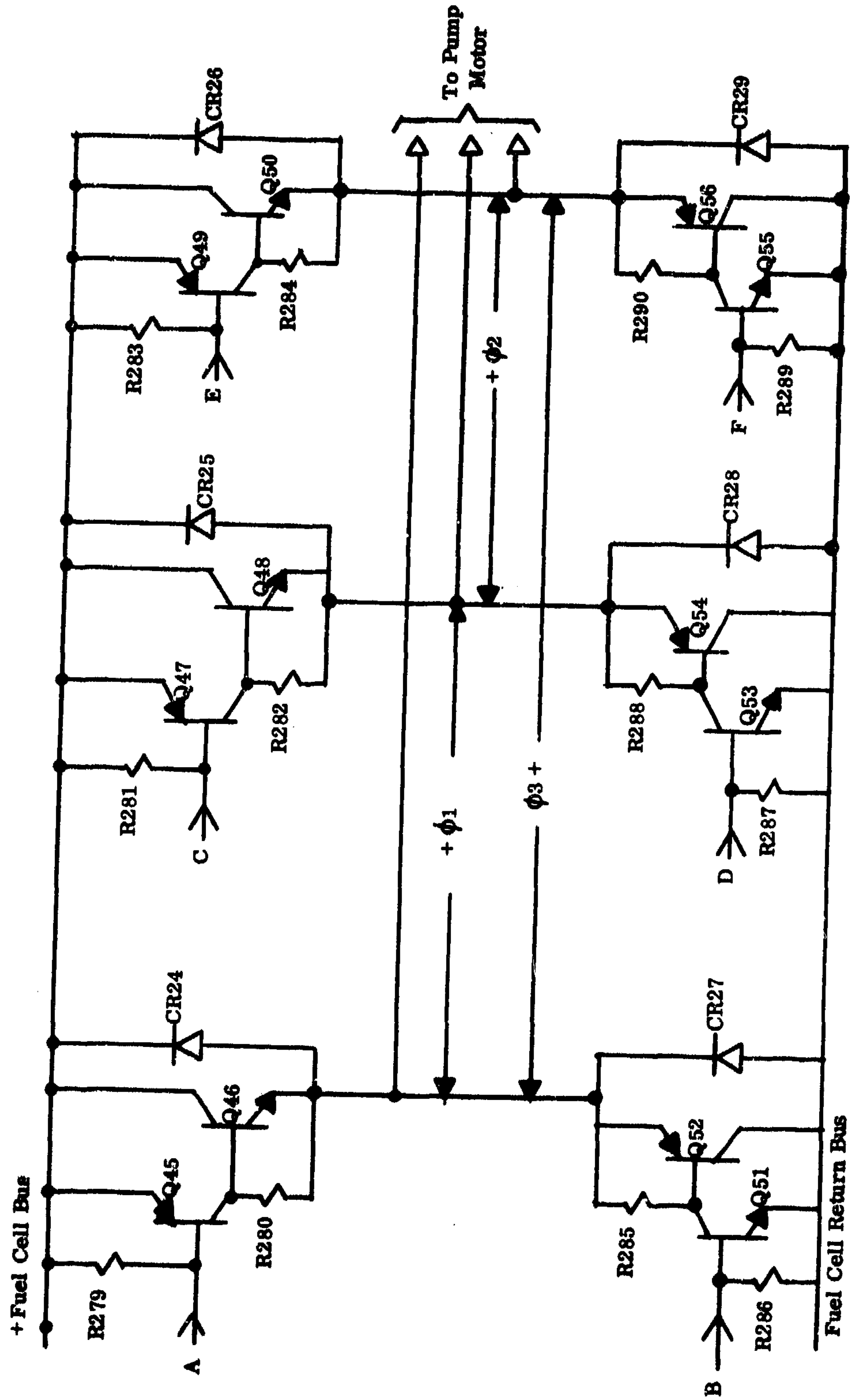


Figure 18. Pump Power Circuitry Electrical Diagram

The resultant line-to-line voltage waveform is shown in Figure 19. The equivalent RMS AC voltage is approximately 1/V2 times the DC level.

2.3.1.4.8 Fan Inverter and Control

The fan inverter and control circuit contains the basic elements of the logic encoding and inverter power circuitry with three additions. There is a variable frequency feature which is dependent upon coolant temperature, a variable voltage control which is dependent upon operating frequency, and step-up transformers to utilize a 115 VAC fan motor drive. The first of these additions, the temperature controlled variable frequency circuitry, is shown in Figure 20. This is a feedback voltage to frequency converter which is set to operate between the limits of 240 Hz and 2400 Hz. This range will be travelled over the input temperature range of 70° to 80°F or 125° to 135°F, depending upon the system it is to be used with. The variable pulse rate output will feed a logic encoding circuit similar to that used in the pump invester.

The variable voltage control will vary the voltage to the fan motor as a function of motor frequency in order to maintain motor current constant. Step-up transformers are added at the output of the inverter in order to match the inverter output level to the motor voltage requirement. A speed sensor is also included.

2.3.1.4.9 System Packaging

The main control electronics assembly comprises the signal conditioning, logic, drivers and inverters necessary to drive all valves, pump, fan and contactor as shown in Figure 21. The auxiliary data assembly houses the amplifiers for the pressure transducers and temperature sensors as shown in Figure 22. Overall system interconnection is shown in Figure 23. Interface connectors pin identifications are displayed on Tables V, VI, and VII.

2.4 Structures

2.4.1 Equipment Bay

The equipment bay has been designed for the following characteristics/ capabilities:

- Vertical landing velocity of 17 ft/sec with 5 G's maximum internal equipment shock.
- Surface winds of 10 knots at landing with 5 G's maximum internal equipment shock.
- Sea landing with swells forming no larger than 45° angle from horizontal with 5 G's maximum internal equipment shock.

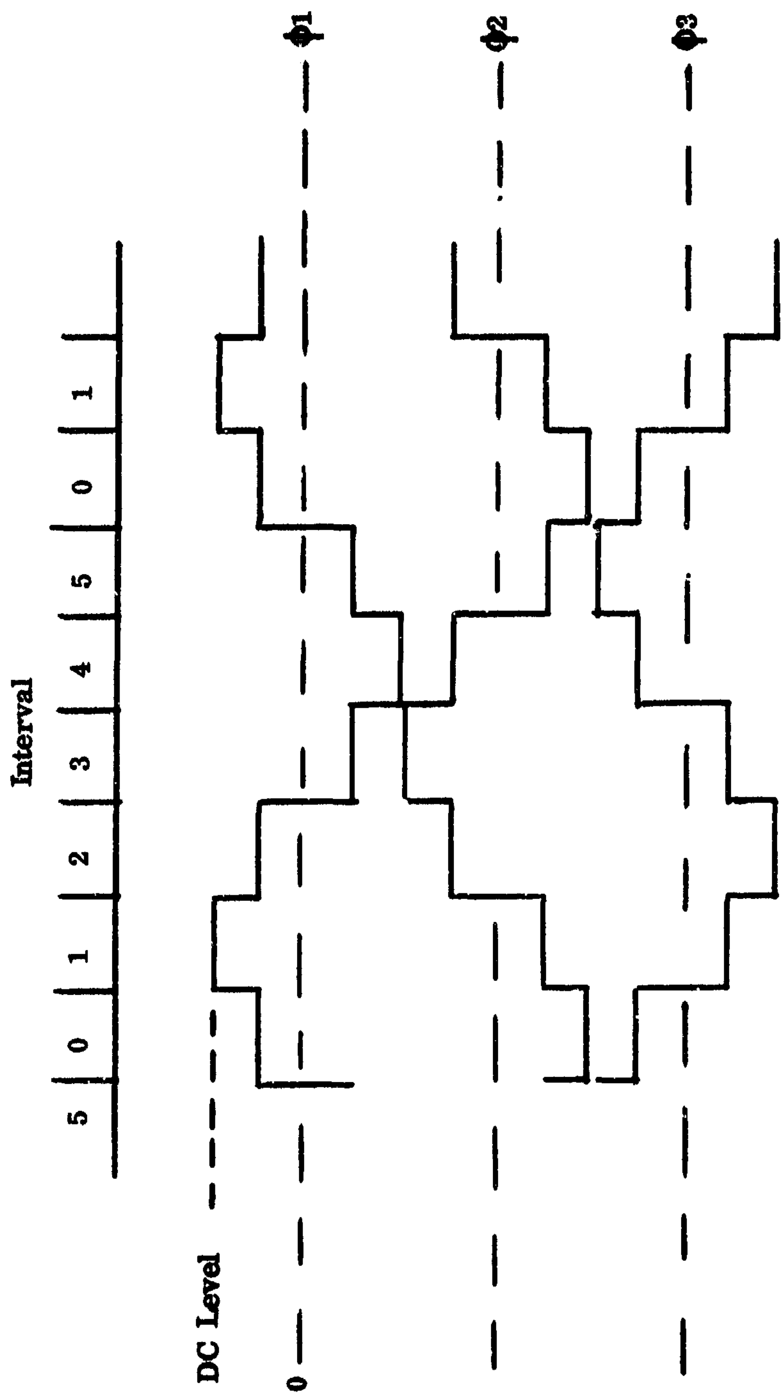


Figure 19. Pump Voltage Waveforms Line-To-Line

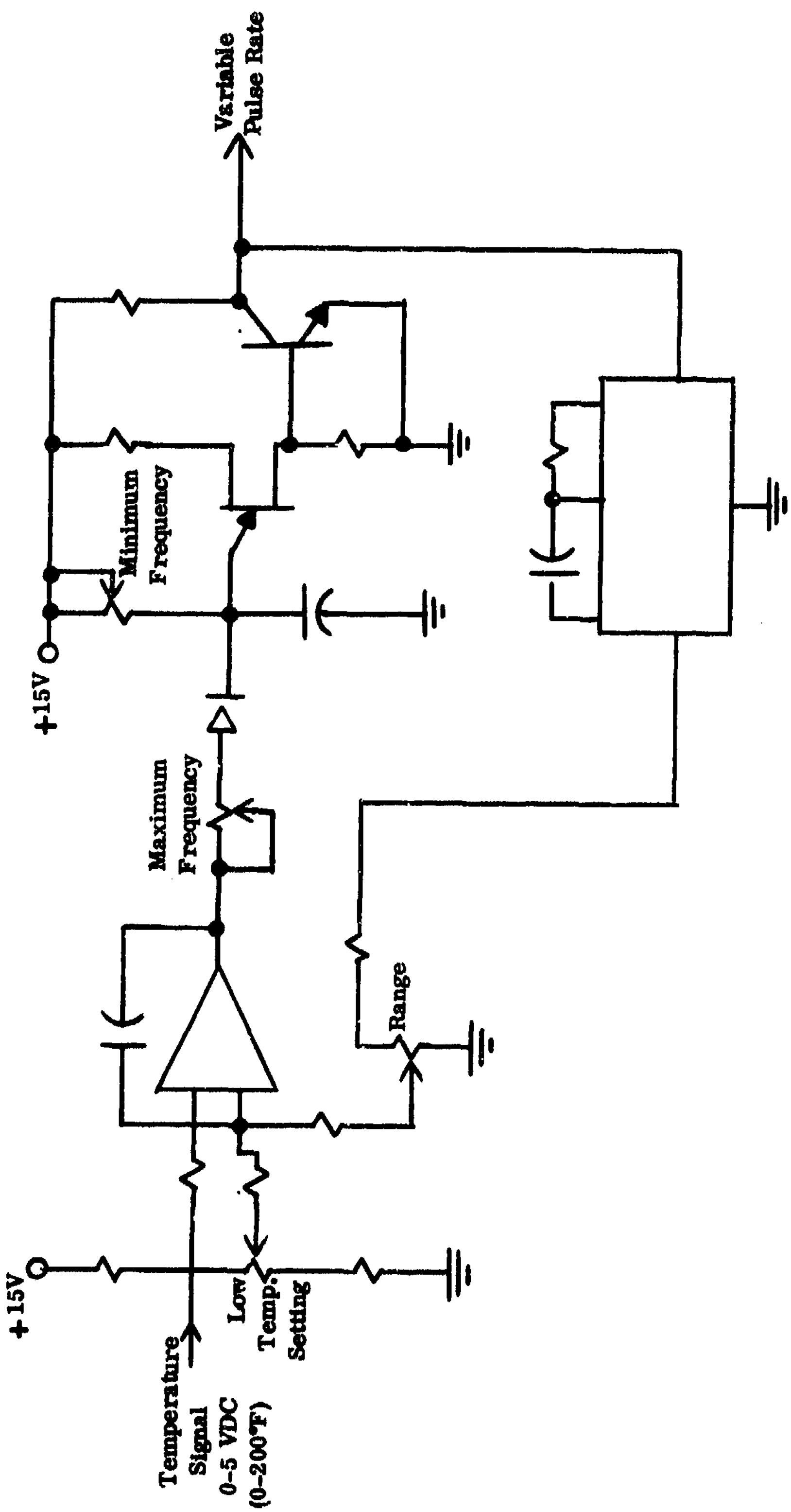


Figure 20. Temperature/Frequency Converter Electrical Diagram

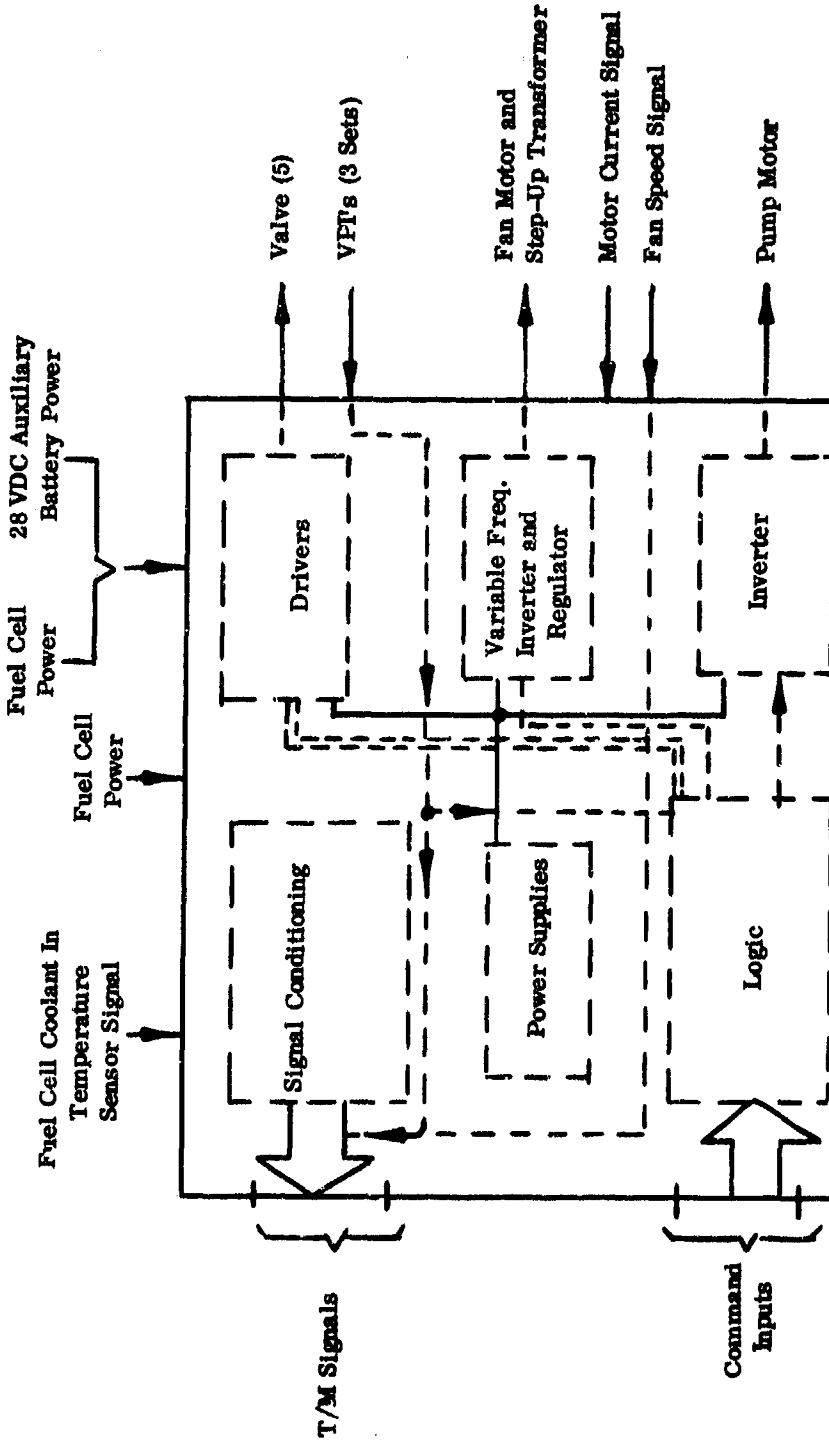


Figure 21. Control Electronics Assembly

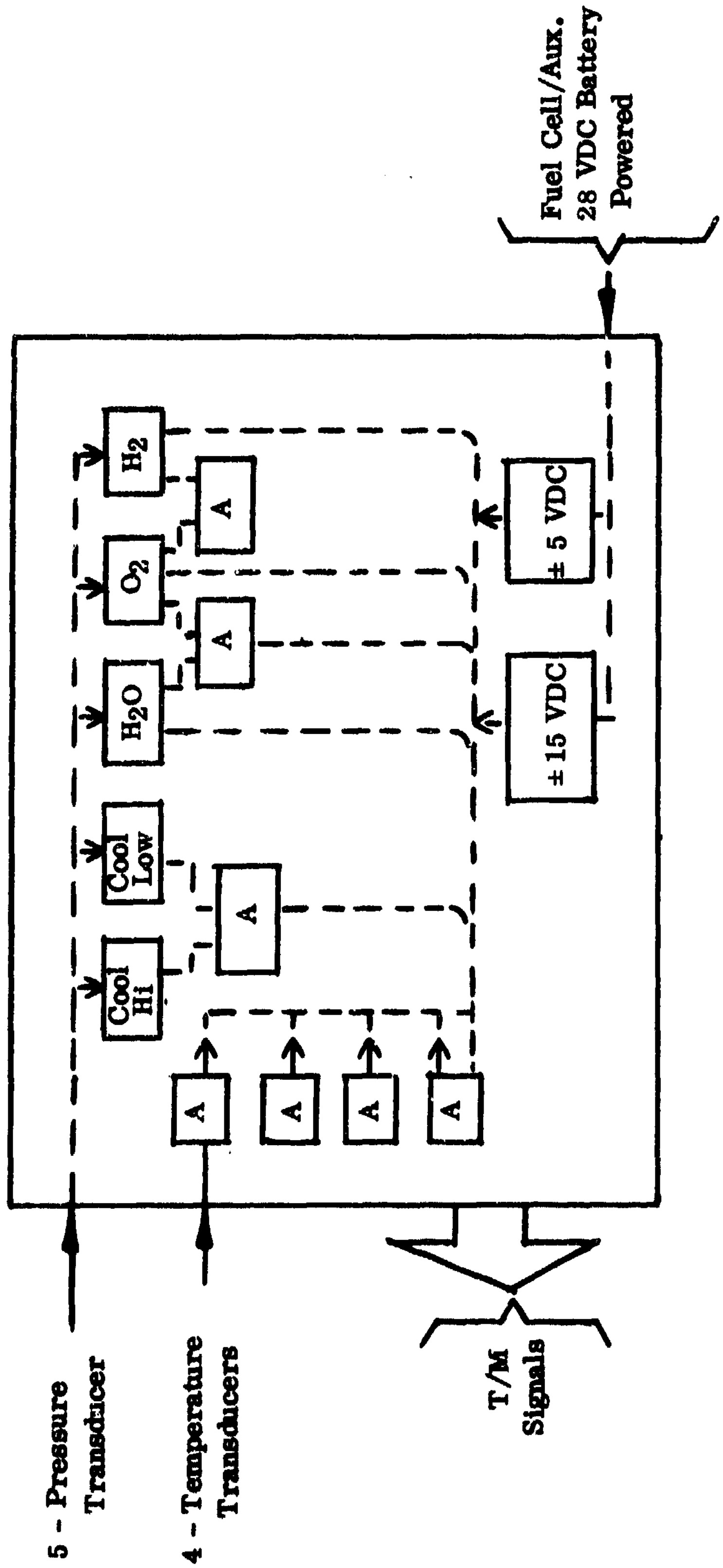
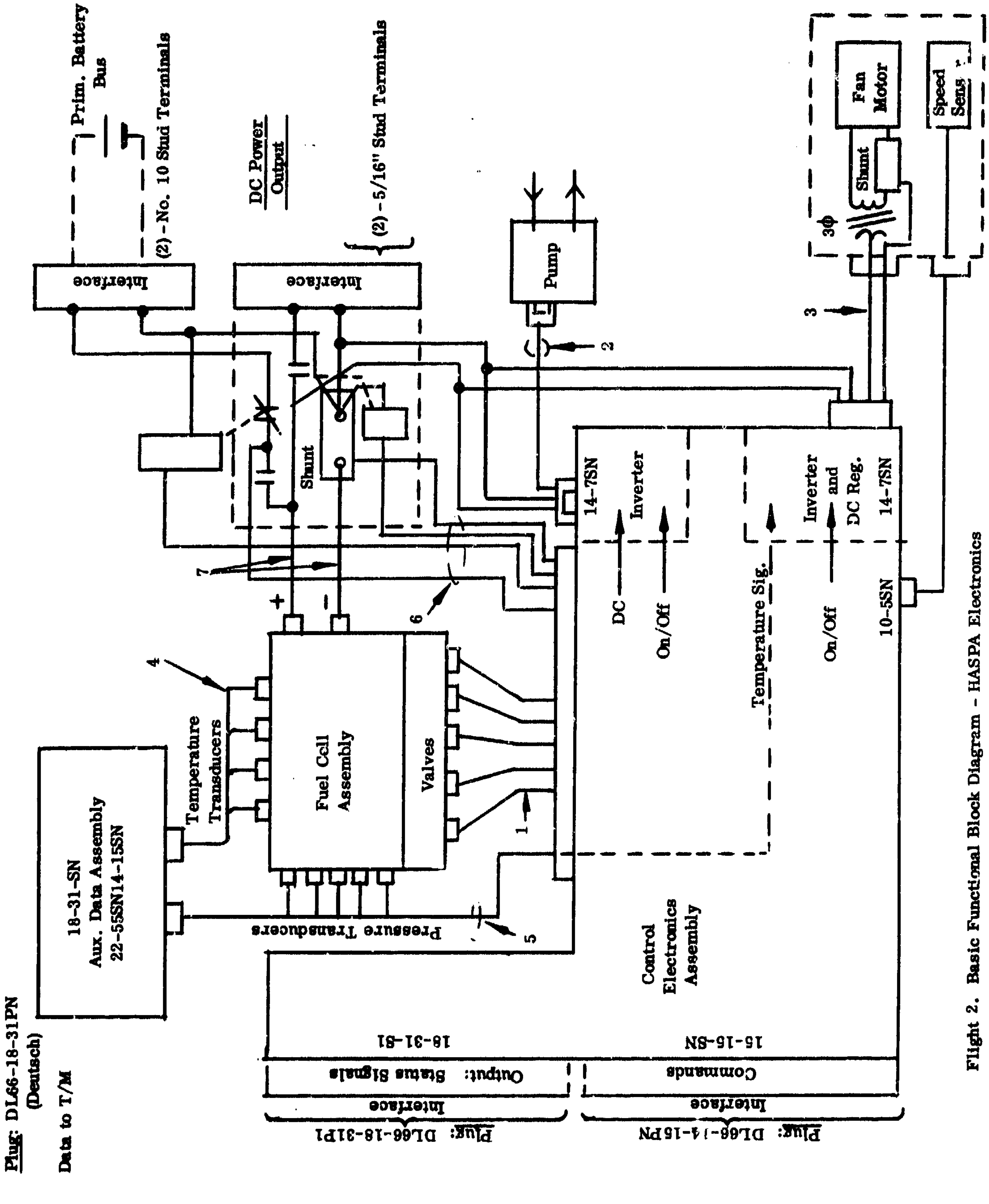


Figure 22. Auxiliary Data Assembly



Flight 2. Basic Functional Block Diagram - HASPA Electronics

Table V

Pin Identification

Fuel Cell Control Unit

Connector DL66R1415PN059-2	(Commands In)
1	H_2 Inlet Open
2	O_2 Inlet Open
3	H_2O Valve Open
4	H_2 Evacuation Open
5	O_2 Purge Open
7	ESD Reset/Override
9	Contactor Close
11	Pump "On"
13	Fan "On"
15	Common

Table VI

Pin Identification

Fuel Cell Control Unit

Connector DL66R18-31P1-059-2	Data Out	*
8	H_2 Inlet Open VPI	D
9	H_2 Inlet Closed VPI	D
20	O_2 Inlet Open VPI	D
21	O_2 Inlet Closed VPI	D
22	H_2O Valve Open VPI	D
23	H_2O Valve Closed VPI	D
12	H_2 Evacuation Valve Open	D
24	O_2 Purge Valve Open	D
3	Emergency Shutdown	D
25	Contactor Closed	D
26	Pump On	D
27	Fan On	D
5	Fan Speed	A
15	Fuel Cell Current	A
16	Fuel Cell Voltage	A
18	Common	

* D - Discrete
A - Analog

Table VII

Pin Identification

Fuel Cell Auxiliary Data Unit

Connector DL66R18-31PN059-2		
6	Fuel Cell In Temperature (Coolant)	A
7	Fuel Cell Out Temperature (Coolant)	A
1	Heat Exchanger In Temperature (Coolant)	A
8	Heat Exchanger Out Temperature	A
15	H_2 Pressure	A
14	O_2 Pressure	A
3	H_2O Pressure	A
13	$O_2 - H_2$ ΔP	A
12	$O_2 - H_2O$ ΔP	A
11	Coolant ΔP	A
2	Common	

* A - Analog

- Water tight construction of bay to protect internal equipment from salt water.

- Floatation of bay in the unlikely event of sea water leakage into equipment area.

- Parachute opening shock of 2.3 G's on equipment and equipment bay.

- Four point suspension.

- Internal temperature control between 40°F and 130°F. for powered flights.

Figure 24 shows the basic outline dimensions of the equipment bay and landing pad.

- The main heat exchanger and cooling fan are located outside the sealed areas so as to use the ambient air for cooling. This requires leaktight joints for coolant inlet and outlet fluids as they pass through the sealed compartment. The salt water exposure of the heat exchanger and fan motor may make these items expendable after only one flight.

- The sealed compartment is able to vent gases for four separate events:

  1. Ambient air pressure during ascent.

  2. Air displacement by product water.

  3. Periodic fuel cell oxygen purging.

  4. Cryogenic tanks boil off to ambient outside the sealed compartment.

- During descent the sealed compartment will refill with ambient air to prevent collapse from the increasing outside ambient pressure, but will not allow the entrance of sea water.

The equipment bay layout for the fuel cell powered flight III is shown in Figure 25.

The equipment bay primary battery location layout (flight II) is shown in Figure 25A.

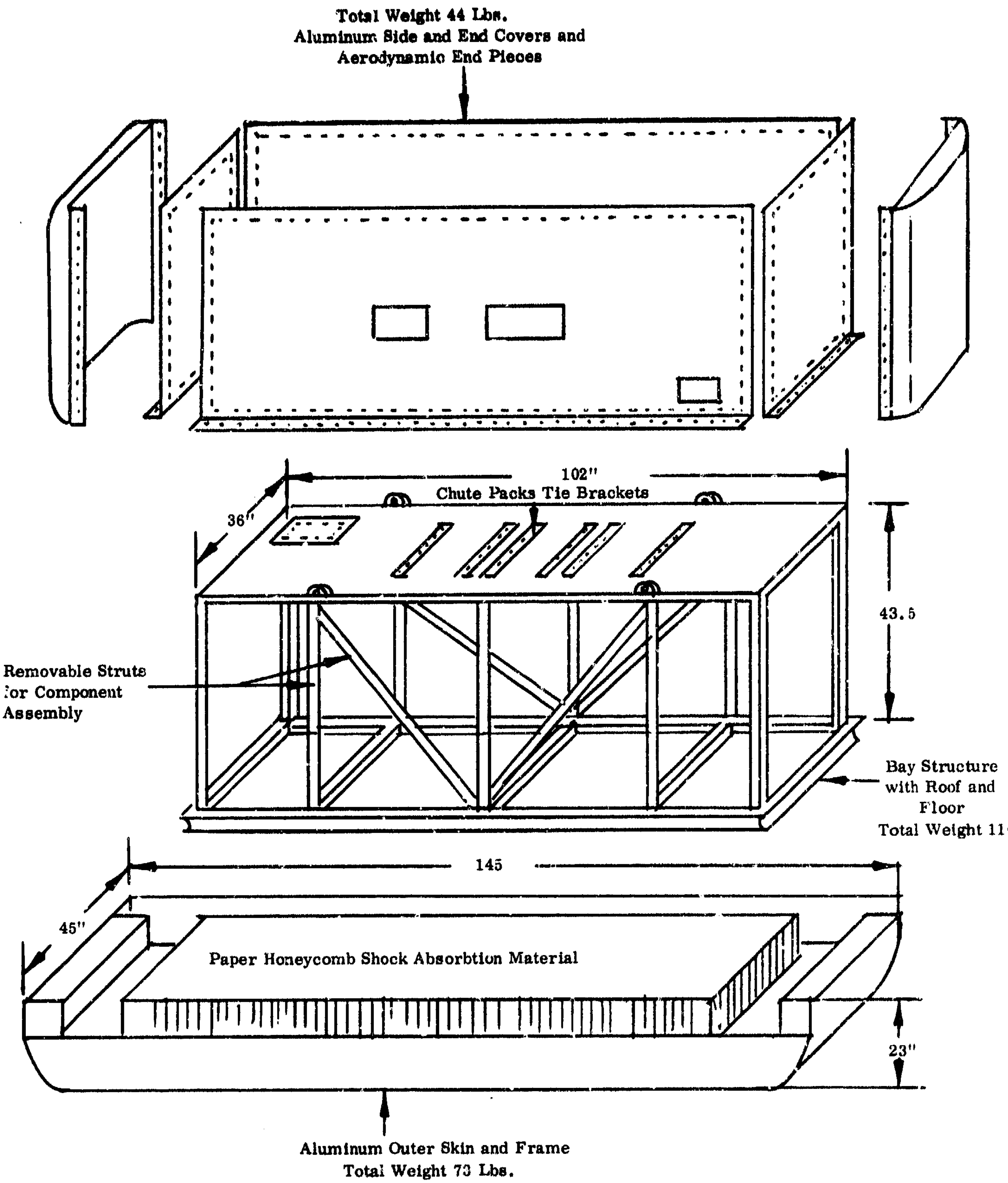
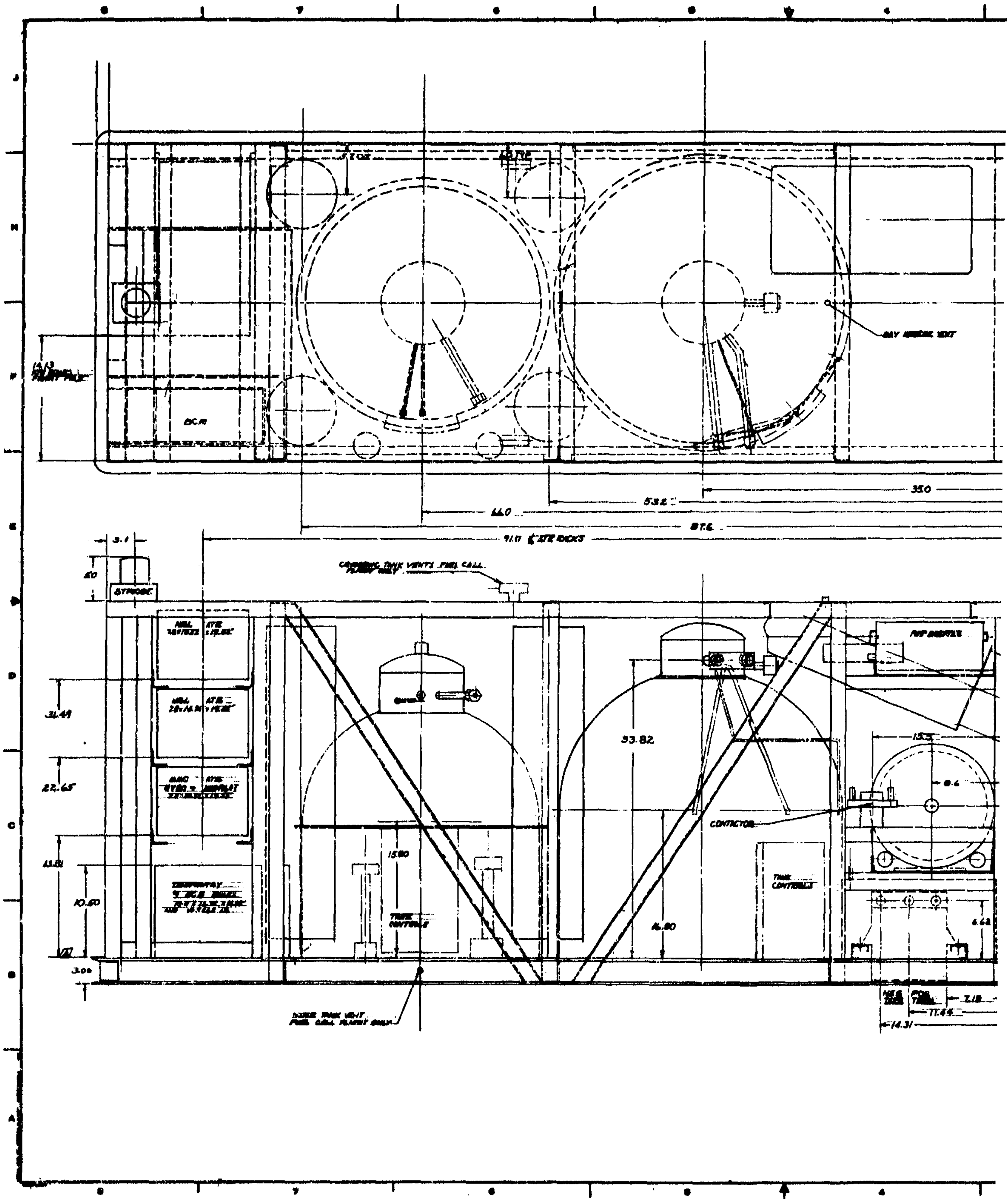


Figure 24. Equipment Bay and Landing Pad

1



53.2
35.0
66.0
87.6
91.0 ℄ ATE RACKS
3.1
5.0
STROBE
BCR
33.82
CONTACTOR
15.80
16.80
31.49
22.65
10.60
3.00
TANK CONTROLS
15.5
8.6
6.62
7.18
11.44
14.31

2

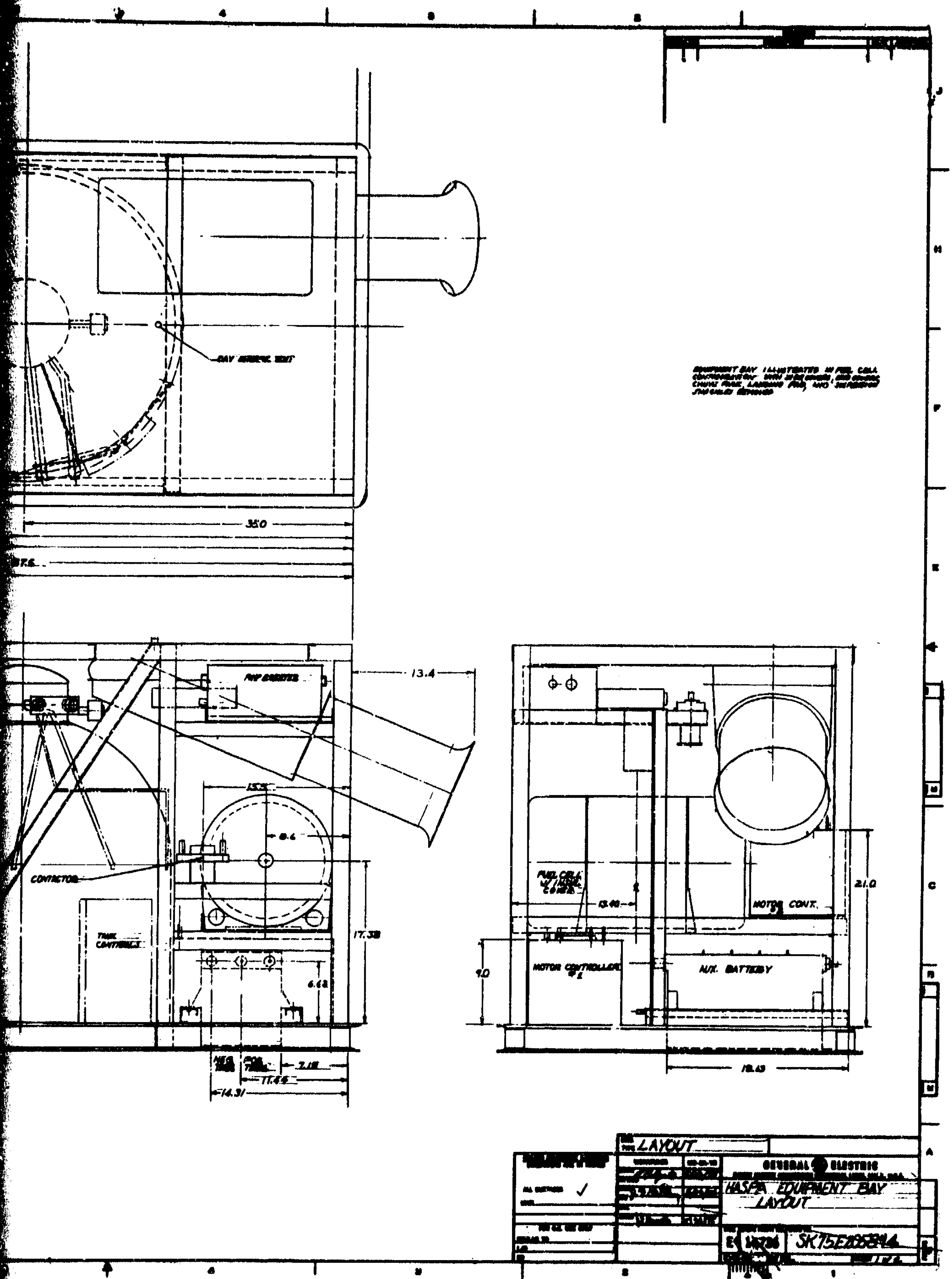
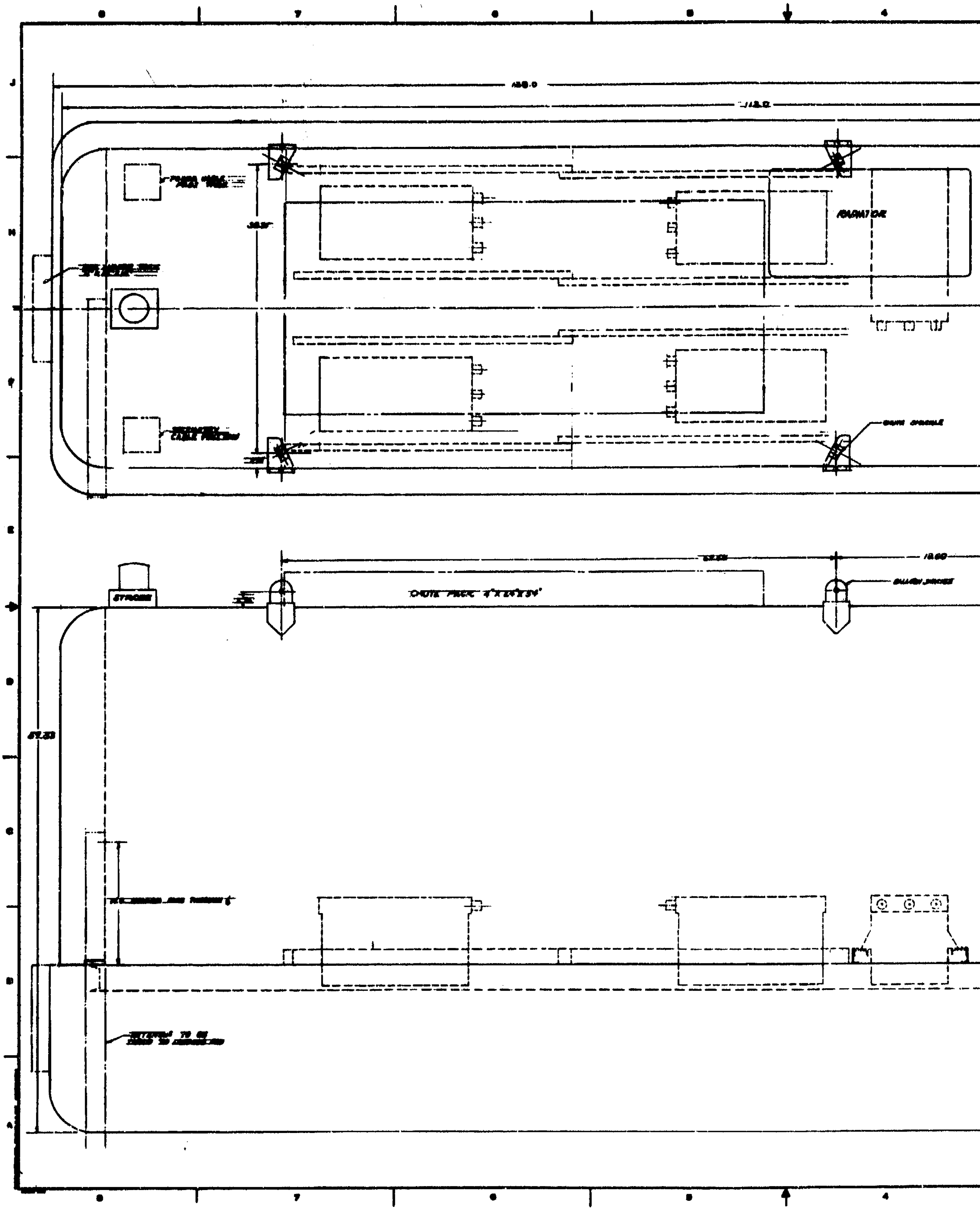

35.0
13.4
CONTACTOR
15.5
8.4
17.38
6.62
14.31
MOTOR CONT.
21.0
9.0
MOTOR CONTROLLER
AUX. BATTERY
LAYOUT
GENERAL ELECTRIC
HASPA EQUIPMENT BAY
LAYOUT
SK75E208814

Figure 25.



RADIATOR
STROBE
CHUTE PACK 4" X 24" X 34"

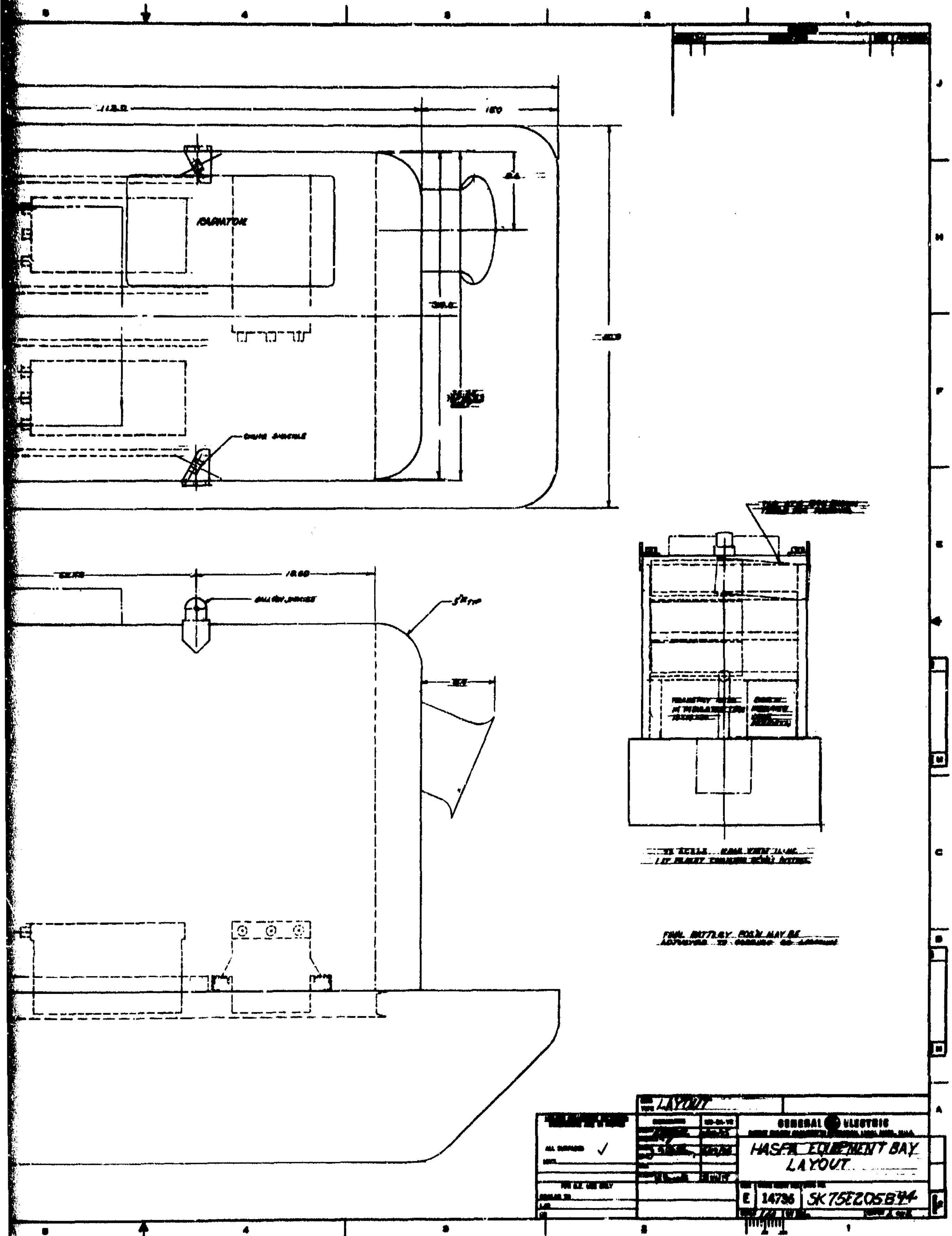

RADIATOR
LAYOUT
GENERAL ELECTRIC
HASPA EQUIPMENT BAY LAYOUT
14736
SK75E205B44

Figure 25. A.

A weight breakdown for the fuel cell powered flight (Flight #3) is displayed on Table VIII. This weight includes the collapsible landing pad. The primary battery flight weight has been modified by a reduction from six to five batteries to achieve similar margins.

Table VIII

HASPA

Equipment Bay Weight Estimates (Flight #3)

H_2 Fuel Tank Mounting Skirt and Fuel		114 (Act.)
Oxygen Fuel Tank Mounting Skirt and Fuel		340 (Act.)
Fuel Tankage Control Box		6 (Est.)
Fuel Cell and Container, Valves and Regulators (dry)		97 (Act.)
Water Tank		23 (Est.)
Coolant Weight		10 (Est.)
Coolant System (dry)		32 (Act.)
Inverters, Converters, Transformers, Control Box, etc.		46 (Est.)
Critical Bus Battery		135 (Act.)
	Power System Total	803
Telemetry Box		100 (Est.)
Navigation Equipment		30 (Est.)
Other		30 (Est.)
Cables		40 (Est.)
	Total - Housekeeping Equipment	200
Parachutes and Mountings and Cases		37 (Est.)
Release Mechanism		4 (Est.)
Location Beacons, Etc. (after landing)		3 (Est.)
	Total - Suspension and Separation Equipment	44
Equipment Bay Platform Structure and Roof		110 (Est.)
Outer Cover		44 (Est.)
Honeycomb Landing Pad		73 (Est.)
	Total - Equipment Bay Structure	227
	Total Estimate This Time	1 274 Lbs.
	Maximum Spec. Weight	1 270 Lbs.

3.0 STORAGE AND SHIPPING CONDITIONS

3.1 Storage Conditions

3.1.1 General

The equipment bay shall be handled at all times with caution to prevent physical damage.

Installed coolant systems shall be opened to ambient air and allowed to drain. Ambient air shall then be locked in at atmospheric pressures.

All batteries will be stored in an unfilled condition.

The fuel cell module shall have been deactivated in accordance with Paragraph 4.2.5.

3.1.2 Environmental Conditions

Ambient temperature shall be controlled between 32 and 150°F. In particular, the full cell stack should not be allowed to freeze as a performance loss will be encountered.

The fuel cell stack shall be stored or shipped with 1.5 to 2.5 psi helium "locked in" the oxygen and hydrogen systems. The coolant system on all flight configurations shall be stored or shipped with ambient air "locked in" at atmospheric pressure.

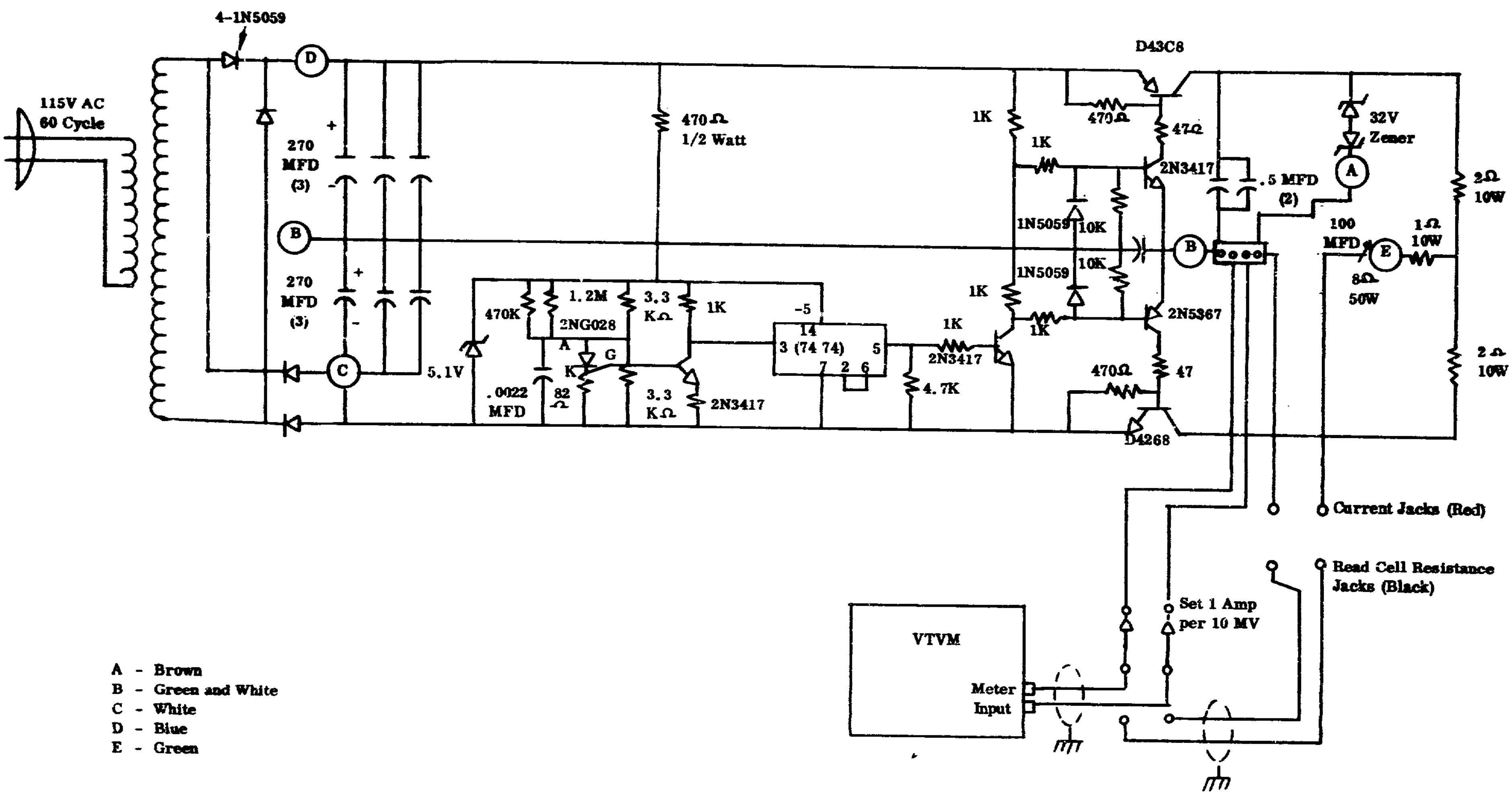
The equipment bay and its components shall be protected in storage or shipment against water, rain, salt sea atmosphere, sand, and dust. It shall not be subjected to unnecessary shock, acceleration, or vibration.

3.1.3 Fuel Cell Module Impedance

The fuel cell module impedance shall be measured and recorded upon putting the module in storage and once per month thereafter. Increased impedance with time may indicate moisture loss from the fuel cell stack. See Figure 26, 1000 Hz Impedance Bridge.

3.2 Shipping Conditions

Prior to shipment, the equipment bay and all components shall be inspected to assure that all parts are firmly secured.



A - Brown
B - Green and White
C - White
D - Blue
E - Green

Figure 26. 1000 Hz Impedance Bridge

Extreme care shall be used in handling of the equipment bay to prevent physical damage to the container and/or components.

During shipment, the equipment bay and components shall not be subjected to environmental conditions in excess of those listed below:

Ambient Temperature: 32 - 150°F

Protect against water, rain, salt sea atmosphere, sand and dust.

The equipment bay and components shall not be dropped or bounced and shall be restrained from sliding or other movement during transportation.

The various systems within the equipment bay will be shipped in the "as stored condition" described in Paragraph 3.1.

4.0 OPERATING INSTRUCTIONS

This section provides instructions for operation of the fuel cell power supply for pre-flight checkout.

4.1 General Instructions

Prior to testing, a visual inspection of the fuel cell power supply, the equipment bay and related components shall be made to insure that shipping and/or storage related damage has not occurred. A fuel cell module impedance measurement should also be taken at this time.

4.1.1 Materials

Materials used during testing should conform to the requirements of Paragraph 2.2.

4.1.2 Equipment and Test Facilities

Equipment used during testing should conform to the requirements of Paragraph 2.2.

All tubing, gauges, valves, pumps, tanks, regulators, etc., should be of high quality stainless steel construction or be installed in a non-contaminating portion of the support facilities.

All testing shall be conducted in a manner to provide maximum protection for the fuel cell power system, support facilities, and operating personnel.

4.1.3 Environment

During gas admission to, or pressurization of, the O_2, H_2, or coolant system, admission of air with hydrogen shall be avoided both with the fuel cell power supply and supporting test equipment.

4.2 Test Sequence

The test sequence for Fuel Cell Power System (Module FS-2) will be as follows:

(a) Verify supporting test equipment and supplies exterior to, and connecting within, the equipment bay are leak tight, clean, and connected properly.

(b) Vacuum fill coolant system.

(c) Pressure, leakages and impedance test Module FS-2.

(d) Activate - utilizing a hydrogen system vacuum purge and electrolysis fill.

(e) Determine performance characteristics.

(f) Shutdown and storage or prepare for flight operation.

4.2.1 Vacuum Fill Coolant System

(1) Remove cap from V6 and install temporary soft lines and valves per Figure 27.

(2) Open V6 plus V9 plus V10 - Close V11.

(3) Start vacuum pump and evacuate coolant system to 1 psia. Close V6 and lock in vacuum. Check for leakage via pressure rise.

(4) Close V9 and V10 - Open V6 plus V11 and slowly fill the coolant system with distilled water until the coolant system pressure is 0.0 to 0.5 psi below the oxygen system pressure.

(5) Close V6 thereby locking distilled water in coolant system - shut off vacuum pump.

(6) Vent coolant pump housing to atmosphere.

(7) Remove Figure 27 piping from V6 and cap V6.

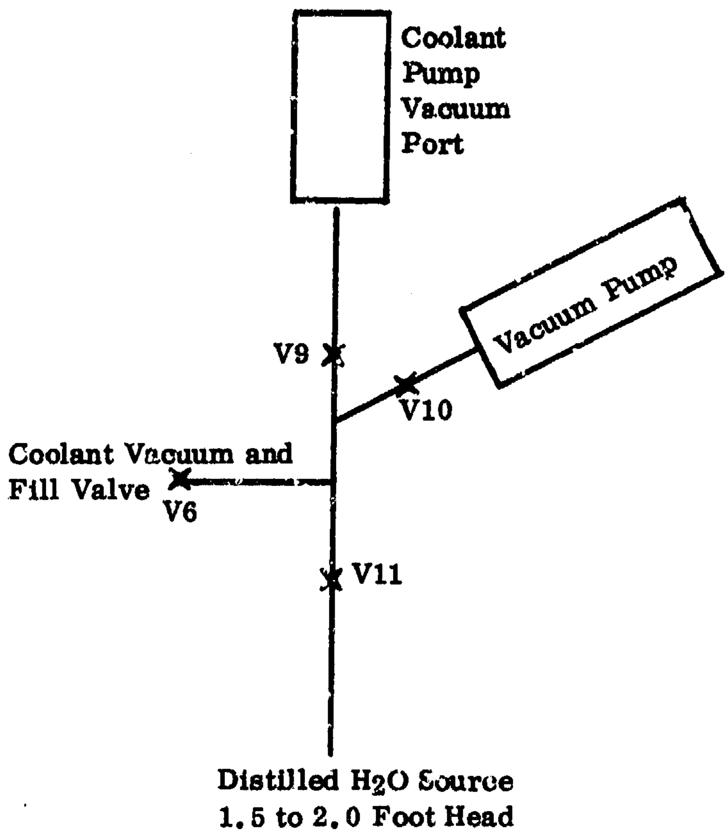
4.2.2 Pressurization, Leakage and Impedance Tests

NOTE: Remove fuel cell power leads and install a 28-volt power supply to the DC power output interface.

CAUTION: Observe proper polarity. Turn on supply. Set 28 volts. Check on M6.

NOTE: See Figure 16 for TM instrumentation readout panels if on TM equipment. Equivalent readouts will be used if not on TM.

(1) Connected externally regulated nitrogen and oxygen sources to V5 and close V4 - Open V5.



Schematic - Vacuum Fill Coolant System

Figure 27.

(2) Open O_2 inlet latch valve and set 5 psig oxygen system pressure with N_2.

(3) Purge O_2 system with 50 liters N_2 thru V8 - perform 3 module O_2 purges via O_2 purge valve.

(4) Evacuate H_2 side to 2 psia maximum by operating the evacuation valve open with a vacuum pump on for 30 seconds. Lock vacuum on H_2 side by closing H_2 evacuation valve.

(5) Note H_2 side pressure rise at 5 minute intervals for 15 minutes (M1).

(6) Open the H_2 evacuation valve and measure the N_2 diffusion rate of the stack by displacement.

(7) Increase the O_2 side pressure to 20 psig N_2 with external regulator.

(8) Repeat steps 4, 5 and 6. Snoop for leakage as necessary.

(9) Repeat steps 7 and 8 at 40 and 60 psig O_2 side pressure with N_2.

(10) Close the H_2 evacuation valve and allow the H_2 side pressure to increase to 56 - 60 psig.

(11) "Snoop" H_2 lines for leakage.

(12) Pull vacuum on H_2 side through H_2 evacuation valve.

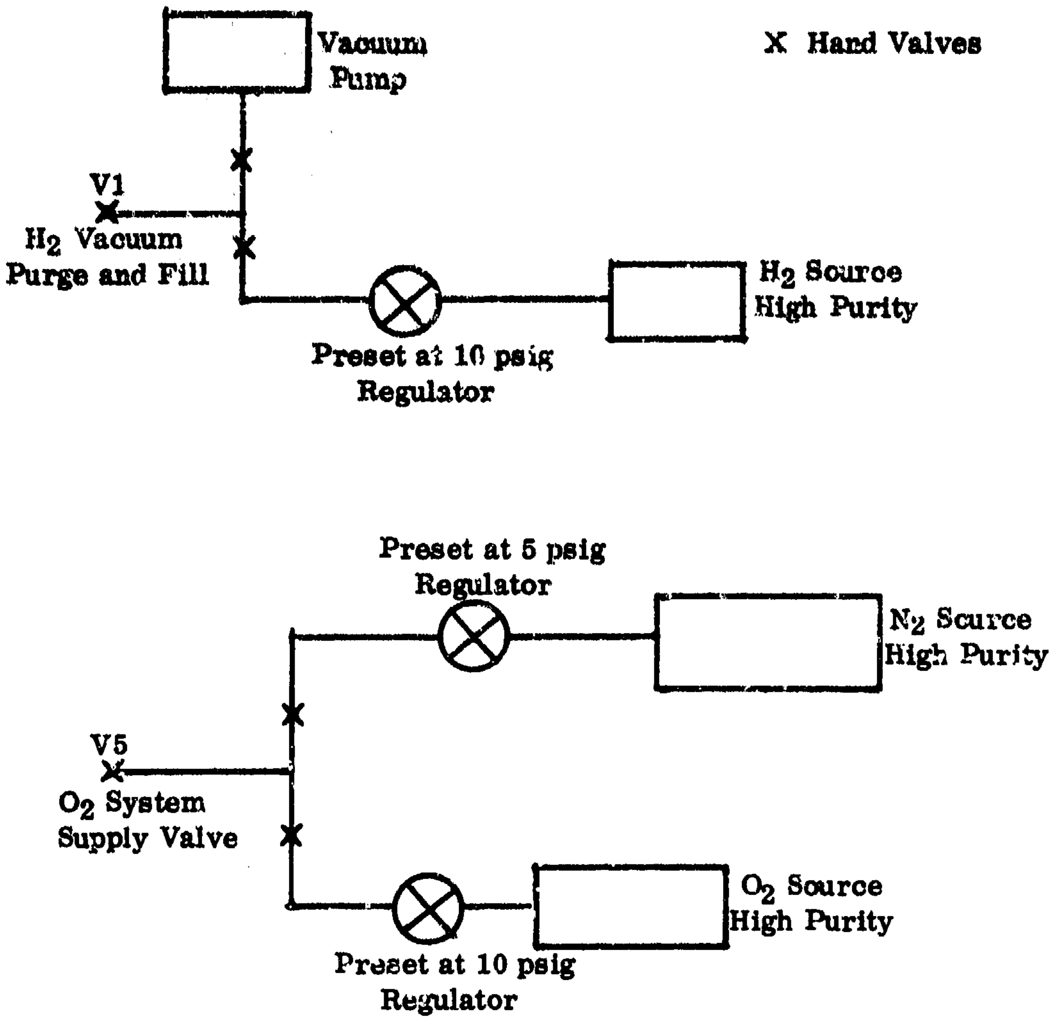
(13) Reduce O_2 side pressure to 10 psig N_2.

(14) Perform 1000 Hz impedance of module.

(15) Connect an externally regulated H_2 source to V1 with provisions for a vacuum line to V1. Assure external H_2 supply regulator is preset at 10 psig.

(16) Evacuate H_2 inlet system up to the H_2 inlet valve (latching). Assure V2 is closed - open V1 and V3 with the vacuum pump on.

(17) Shut off vacuum pump valve and introduce pure H_2 to the module up to the H_2 inlet latch valve at the preset pressure of the external H_2 regulator (10 psig). See Figure 28.



Module O_2 and H_2 Preflight External Test Connections for Para. 4.2.2

Figure 28.

4.2.3 Activation - Startup (H_2 System Vacuum Purge with Electrolysis Fill)

(1) Start coolant pump and assure coolant flow by monitoring coolant ΔP (M2).

(2) Cross-over from N_2 to O_2 externally and purge 50 liters of pure O_2 thru the oxygen system by opening the module container bleed valve (V8). Purge O_2 stack by energizing O_2 purge valve three times.

(3) Draw a vacuum to 2 psia maximum on the H_2 system via the H_2 evacuation valve.

(4) Connect a DC power supply (35 amp - 70 volt capability) to the fuel cell power leads (Cable 7, Figure 23). The positive lead of the power supply must be connected to lead identified as positive in Cable 7. Connect negative power supply lead to negative lead of Cable 7.

(5) Perform a 35 ampere module electrolysis for 10 minutes with live vacuum on the H_2 side. Purge O_2 from the stack periodically to maintain 10 psig on the O_2 system. Monitor O_2 pressure on M1.

(6) During electrolysis confirm a 10 psig hydrogen source pressure. Open the H_2 inlet latch solenoid valve and allow additional H_2 system purging to the vacuum.

(7) Drop the electrolysis load and close the H_2 evacuation solenoid valve. Verify 10 psig O_2 pressure and 6 psig H_2 pressure by instrumentation readouts. Shut off coolant pump.

(8) Disconnect both the DC power supply and the DC electrolysis power supply.

(9) Reconnect fuel cell power leads (Cable 7) to DC power output connections. The connections are sized to prevent improper polarity connection.

(10) Check TM instrumentation readout panels. Read M6 E_T.

Note: The disconnection of the DC power supply and connection of the fuel cell power supply results in a period of open current and subsequent automatic shutdown. Reset ESD when the fuel cell power supply is connected. Proceed with readouts as per this instruction.

#1 Meter Panel - Verify H_2 and O_2 pressures.

#4 Light Indication Panel - H_2 and O_2 latch valves should be ON (Green). All other lights OFF.
(Restore latch valves H_2 and/or O_2 to ON (Green), if necessary.

(11) Turn on coolant pump. Monitor coolant ΔP (Meter 2) to verify coolant flow. Check Meter 5 for pump current (I_T) and E_T (M6).

(12) Turn on fan. Again check E_T and I_T. Purge module O_2 side as necessary to maintain performance.

(13) Increase load to 15 ampere level.

(14) Open H_2O latch valve.

(15) Slowly raise external facility pressure to 100 psig O_2 and 100 psig H_2.

(16) Check all twenty-four instrumentation readouts* for "in tolerance" conditions. Check purge time and interval to verify (8-10 seconds/ 16 amp hours).
* Table III and Figure 10.

4.2.4 Performance Checkout

(1) Set 55 ampere load and allow coolant temperature to stabilize at 130°F.

(2) Check module voltage at 15, 30, 60 and 120 amp, or maximum load for comparison with previous HASPA data (Figure 1).

(3) Reset 55 amp load and allow stabilization. Proceed to Paragraph 4.2.5 or 4.2.6 as the situation warrants.

4.2.5 Shutdown and Storage

(1) Open load contactor.

(2) Close H_2O valve.

(3) Allow system to cool to approximately 100°F.

(4) Close H_2 In latch valve and override emergency shutdown. Close hand valve to H_2 source (Figure 28).

(5) Allow oxygen takeover until H_2 side pressure is above ambient.

(6) Stop coolant pump.

(7) Open H_2 evacuation valve. Perform O_2 to H_2 leak check at 60 psid O_2 by displacement.

(8) Reduce O_2 pressure to 5 psig.

(9) Install helium source in place of nitrogen at O_2 system supply valve (see Figure 28).

(10) Purge 50 liters helium thru O_2 side of module.

(11) With H_2 evacuation valve still open, close O_2 inlet latch valve and reduce O_2 side helium pressure to 2.5 psig.

(12) Close H_2 evacuation valve. Allow emergency shutdown to function (eliminate override).

(13) Evacuate H_2 inlet system up to H_2 inlet valve.

(14) Open V6 - coolant vacuum and fill valve. Drain at ambient pressure. Close V6.

(15) Record 1000 Hz impedance of module.

(16) Remove external pressurization, leakage and operational materials and equipment.

(17) Store equipment bay per Section 3.0.

4.2.6 **Preflight System Checkout**

(1) Reduce load to 0 amperes. Coolant OFF - Fan OFF.

(2) The O_2 and H_2 cryogenic storage systems must be ready for flight at this time, top off complete and checked out by the contractor. If so, cross over to cryogenic H_2 (see Figure 2).

(3) Turn on coolant and fan.

(4) Set 15 amp load. Check instrumentation readout panels.

(5) Set 55 amp load.

Observe performance increases or decreases. Stabilize 15 minutes. During stabilization, drain product water storage system by opening V7. Close V7 as soon as product water ceases to flow. (See Figure 2.)

(6) Cross over to cryogenic O_2 (see Figure 2). Observe performance change. Stabilize 15 minutes. During stabilization, remove all equipment external to V1, V5 and V6. Cap V1, V5 and V6 (see Figure 2).

(7) Stabilize at 130°F coolant temperature. Assure that performance data is similar to that obtained in Paragraph 4.2.4, Step 3.

(8) Verify all input commands are functioning properly by individual operation and monitoring of meters or lights. Record a complete set of fuel cell power supply TM data.

(9) Secure equipment bay for Flight Number III per Paragraph 2.4.1.

5.0 REMEDIAL ACTION

5.1 Abnormal Indications

5.1.1 Emergency Shutdown (Module Voltage Below 10 Volts)

Performance at a level low enough (10 volts) to cause an automatic emergency shutdown results in a red shutdown light on the light indication panel, closes all valves, and shuts off power to the coolant pump, fan, and propulsion load. If this condition occurs:

IMMEDIATELY: Switch all TM power system input commands to the safety mode which is:

Pump, Fan and Load Contactor = OFF
All Valves = CLOSED

The TM input commands must be switched to the safety mode to prevent possible damage to the fuel cell module when a reset is attempted.

Monitor ET, IT, H_2/O_2 ΔP, H_2 Psia and O_2 psia.

The H_2/O_2 ΔP should be slowly increasing.

H_2 Psia should be slowly decreasing.

O_2 Psia should be 60 or 75 Psia and steady.

ET should be 34.0 + Volts.

IT should be 0.0 amperes.

If the above conditions are satisfied:

1) Operate emergency shutdown/reset command.
2) Open H_2 In latch valve - monitor pressure.
3) Open O_2 In latch valve - monitor pressure.
4) Turn on coolant pump - monitor ET plus IT.
5) Turn on fan - monitor ET plus IT.
6) Record all TM instrumentation readouts and, if normal, close load contactor and continue mission.

If the shutdown conditions are not satisfactory as previously described, allow the power system to continue as is, which will result in an O_2 takeover of the H_2 side. This is the safest way to proceed and enables safe shutdown and efficient start-up, if warranted. Switch power system input commands to the safety mode which is:

Pump, Fan and Load Contactor	=	OFF
All Valves	=	CLOSED

Further investigation of the malfunction is necessary at this time to verify system operational capabilities.

5.1.2 Low Module Performance

Low module performance is described best as performance one to two volts below Figure 1 - Performance Data.

This problem will most probably be encountered after long term storage or excessive time at open circuit and is associated with contamination of or excess water in the cathode electrode. Performance levels are restored by a repeat electrolysis and/or high load operation.

5.1.3 Panel Light or Meter Readout

Abnormal panel light indication or associated component malfunction can be pinpointed by monitoring the meter readouts of the suspect parameters in the load and/or no load fuel cell condition. If at pre-flight testing, the necessary repairs should be made.

Problems of this nature that might occur during flight missions can be analyzed as above and thus lead to a methodical decision as to safe operation during the remainder of the mission.

6.0 FLIGHT INSTRUCTIONS (MODIFICATIONS)

6.1 Flight I (Non-Powered)

Water tight covers will be installed on the equipment bay at the fan intake and main heat exchanger areas (Figure 25). The front, back and side covers may be removed for the installation of equipment at pre-launch, if required. Any removed covers will have to be resealed when reinstalled utilizing RTV-108 sealant between frame and cover to prevent sea water entrance into the equipment bay at recovery. The equipment bay will be shipped from General Electric/DECP as described.

The landing pad will be shipped with the equipment bay, but protected against possible damage or overload during handling.

6.2 Flight II (Battery Powered)

The equipment bay will be modified by installation of the main heat exchanger and fan intake. The additional equipment and controls necessary to support Flight II will be installed at the flight site. See Figure 8 - Cooling System Fluid Schematic. Coolant system filling will be performed per Paragraph 4.2.1 except that the fuel cell will be replaced with a gas pressure accumulator which will be pressurized to 45 psig with nitrogen and locked in place. Reinstallation of removed covers will be resealed utilizing RTV-108.

The input command, meter readout, and light indication panels, as listed in Table II and Table III will be utilized where applicable.

The TM instrumentation readout panels will conform to Figure 16.

See Figure 3 for a block diagram of HASPA power system electronics.

The landing pad will be removed after Flight I and a new landing pad installed at the flight site for Flight II.

6.3 Flight III (Fuel Cell Powered)

The equipment bay will be fitted with a new landing pad and the fuel cell module FS-2 and all supporting and supported equipment installed as per the detailed operating instructions and schematics of this report. All installation of equipment will take place at the launch site.

6.4 Flight IV (Solar Cell/Battery Powered)

Modification on site will consist of removing those portions of the fuel cell power system to configure to Figure 9 - Cooling System Fluid Schematic - Solar Cell/Battery Powered Flight.

The instrumentation and electronics will be similar to Flight II.

A new landing pad will be installed.